Office of Technology Assessment

Congressional Board of the 97th Congress

TED STEVENS, *Alaska, Chairman*

MORRIS K. UDALL, *Arizona, Vice Chairman*

Senate	House
ORRIN G. HATCH *Utah*	GEORGE E. BROWN, JR. *California*
CHARLES McC. MATHIAS, JR. *Maryland*	JOHN D. DINGELL *Michigan*
EDWARD M. KENNEDY *Massachusetts*	LARRY WINN, JR. *Kansas*
ERNEST F. HOLLINGS *South Carolina*	CLARENCE E. MILLER *Ohio*
HOWARD W. CANNON *Nevada*	COOPER EVANS *Iowa*

JOHN H. GIBBONS
(Nonvoting)

Advisory Council

CHARLES N. KIMBALL, *Chairman*
Midwest Research Institute

EARL BEISTLINE
University of Alaska

CHARLES A. BOWSHER
General Accounting Office

CLAIRE T. DEDRICK
California Land Commission

JAMES C. FLETCHER
University of Pittsburgh

S. DAVID FREEMAN
Tennessee Valley Authority

GILBERT GUDE
Congressional Research Service

CARL N. HODGES
University of Arizona

RACHEL McCULLOCH
University of Wisconsin

WILLIAM J. PERRY
Hambrecht & Quist

DAVID S. POTTER
General Motors Corp.

LEWIS THOMAS
Memorial Sloan-Kettering Cancer Center

Director

JOHN H. GIBBONS

This is an OTA Background Paper that has neither been reviewed nor approved by the Technology Assessment Board

J952-21

Impacts of Technology on U.S. Cropland and Rangeland Productivity

Volume II—Background Papers

Part D

Paper No.
19. Impacts of Technologies on Productivity and Quality of Rangelands in the Great Plains Region

December 1982

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

Preface

This volume contains papers written for OTA to assist in preparation of the report *Impacts of Technology on U.S. Cropland and Rangeland Productivity.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

Background Paper No. 19

IMPACTS OF TECHNOLOGIES ON PRODUCTIVITY AND QUALITY OF RANGELANDS IN THE GREAT PLAINS REGION

James K. Lewis
Associate Professor

David M. Engle
Assistant Professor

Department of Animal Science
South Dakota State University
Brookings

December 1980

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

Background Paper No. 19

IMPACTS OF TECHNOLOGIES ON PRODUCTIVITY AND QUALITY OF RANGELANDS IN THE GREAT PLAINS REGION

ABSTRACT

The Great Plains region of the United States, considered in this report, is that vast stretch of grassland extending from Canada to Mexico and from the Rocky Mountains on the west to the deciduous forest on the east. It is characterized by a rigorous continental climate with frequent and somewhat regular cycles of drought and wet years. The history of the region records the failure of the technology of the humid forests of the east to cope with the new challenges of the semiarid to subhumid, treeless plains and prairies. Success was marked by developing new technologies and institutions for new problems. Failure was marked by clinging to old technologies and institutions, or having them imposed from outside the region.

Rangelands of the region total about 250 million acres of which 70, 16, 2 and 11% are in the Plains grasslands, Prairie, Shinnery and Texas savanna, respectively. About 95% of these lands are in private ownership, 1.8% in the National Forest System and 2.2% in the Natural Resource Lands administered by the Bureau of Land Management. About three-fourths of the lands are in fair and poor range condition, by the Forest Service method, with about one-eighth in good and one-eighth in very poor, with better range condition in the northern than in the southern part of the region. Trend in range condition appears to be sharply upward in all states of the region. Bruch encroachment is a serious problem in all states of the region, except Nebraska and South Dakota; is especially severe in portions of Oklahoma, Texas, New Mexico and Missouri; and is becoming worse in Oklahoma, Kansas, and New Mexico.

The resources and uses of the rangelands of the Great Plains region are extremely diverse and very important for the region and the nation. Many of these resources are not fully developed and will require education and incentives for development on privately-owned lands. Forage and habitat for livestock and a great variety of wildlife are especially important. Water resources, minerals and recreation are very important. Ground water resources are being depleted, stream-flow is often low and erratic, with very severe livestock water problems over wide areas. Mineral fuels are important and biomass fuels are potentially important in the region. Research and educational uses have great potential. While there are exceptions, in general, the uses are not directly competitive, but complementary, although development under private ownership may require education and incentives, because of the additional capital and management skills required.

Rangelands deteriorate for a variety of causes, the most common being too many herbivores on the land, whether livestock, game, rodents, rabbits or other. A number of factors predispose toward range deterioration by livestock grazing, including various economic factors, speculative opportunities and various judgment factors. The process of range deterioration by grazing and the characteristics of such depleted ranges are similar on all continents, resulting in a vegetation that is grazing-resistant, drought-resistant and that escapes grazing. In Texas savanna, Shinnery, and Oak savanna, the general effect is a thickening of thorny brush and small trees. In the Plains grassland, the major effect is thickening of the shortgrass sod in the central and northern portion and the increase of mesquite, short-growing grasses and weedy forbs in the southern portion. The smooth operation of the hydrologic cycle is disrupted with reduced infiltration and percolation, increased runoff and increased soil erosion by wind and water. Ecological diversity, habitat quality, forage intake and quality of diet are generally reduced for both livestock and game. Potential for many other uses is also reduced, resulting in lowered net ranch income.

Viable alternatives for range improvement are those which meet the management objectives and solve the problems. They are usually composed of a series of practices which are various manipulations of grazing animals, both wild and domestic, and manipulations of vegetation, site constants and/or driving variables. The use of some practices has been thoroughly researched, while others are incompletely understood and need further research. A vast amount of technology is available in the form of information, equipment, chemicals, etc. which can be used by management. The mathematical tools and computational methods available to assist managers in decision-making are excellent and further advances are being made rapidly.

Ranching, tourism, and mining are the most important businesses using the rangelands of the Great Plains. All of these businesses are being drastically influenced by a long list of national and global trends over which the managers have no control. Increasing world population, exhaustion of resources, increased demand for the products of the land, inflation, high interest rates, etc. place greater stress on management, continually.

The financial status of Great Plains ranches is critical and under stress, especially from drought, high interest rates, high costs of inputs, relatively low product prices, and high land costs. In an effort to meet these stresses ranchers have increased stocking rates, put more land in crop production and turned to higher energy inputs, such as more concentrate feeding, fertilizers, introduced pastures and farmed forages. With higher fuel, machinery and fertilizer costs, these measures are often counter productive. Cultivation of land unsuited for crop production has increased erosion and in many cases, reduced profits. As a result more attention needs to be given to minimizing the use of cultural energy in the production of meat and fiber through production of slaughter animals from rangeland, using optimum combinations of grazing animals, and developing potential uses for optimum diversity of sources of income for maximum flexibility.

The key to rangeland improvement and optimum use of both public and private rangelands is education. The universities are challenged to provide sound professional education in range science for land managers, technical advisers, research workers and teachers, both in degree programs and for updating professional knowledge. They are also challenged to provide an appreciation of range science for those in other disciplines. The Extension Service and the Soil Conservation are challenged to provide adult and youth education for rural people through various avenues. Furthermore, there is a need for education in rangelands, which comprise nearly one-half of the land surface of the earth, for all school children and for the general population, in order to provide an appreciation for the value and the needs of rangelands and the people who manage them.

Technical and financial assistance for landowners is needed to obtain technology transfer from research to application and to make it economical for ranchers to manage so that the goals of society are met.

A very large amount of federal legislation, most of it passed in the past 15 years, impacts directly or indirectly on rangelands and have produced increasing interests in rangelands, provoking new statements of range policy from the U. S. Department of Agriculture and the Bureau of Land Management. These policy statements regard rangelands as ecosystems producing a variety of products and uses and show an excellent view of the importance of rangelands and their products.

The application of the new policies in dealing with the allocation of resources to secure optimum management and development of rangelands will be very challenging. There is a great need to increase the number and the professional competence of those workers dealing with rangelands. More funds are needed for a wide variety of programs. A good data base with sufficient accuracy and precision for management is urgently needed. The restoration of cultivated lands unsuitable for crop production will be costly. Yet the economic ills of the country require a reduction in the size and expensiveness of government. There is indeed a challenge to meet the needs of rangelands in such a period of competition and adjustment. The efficiency of increased state and regional versus federal control must be examined also.

For more than a decade there has been a sustained call for more research workers and greater expenditures on a wide array of critical problems on rangelands. These needs continue to be expressed, but little has been done about it. Recent experimental results from grassland studies in the International Biological Program indicate that research into understanding and manipulating energy flow pathways will be very fruitful and might lead to the doubling of the production of managed grazing animals. The additional impetus of the new Rangelands Research bill is urgently needed.

TABLE OF CONTENTS

Page

TITLE PAGE i

ABSTRACT ii

TABLE OF CONTENTS vii

LIST OF TABLES xi

LIST OF FIGURES xvi

1. INTRODUCTION 1

2. GENERAL DESCRIPTION 2

2.1 Geology and Soils 2
2.2 Climate 7
  2.2.1 Recent Climatic Regime 7
    2.2.1.1 The Average Condition 7
    2.2.1.2 Variability 20
  2.2.2 Possible Future Climatic Regimes 27
2.3 Vegetation 31

3. HISTORICAL PERSPECTIVE 38

3.1 Pre-Columbian 38
3.2 Period of Exploration 38
  3.2.1 Spanish and French Period (1530-1803) 38
  3.2.2 American Period (1804-1846) 40
3.3 Settlement East and West of the Plains (1846-c1875) 42
3.4 Settlement and Attempted Conquest of the Plains, 1876-1945 45
  3.4.1 The Record 45
  3.4.2 Reasons for Failure 49
    3.4.2.1 The Technologies, Attitudes and Institutions of the Humid East Were Unsuited to the Subhumid and Semi-arid Plains 49
      3.4.2.1.1 Changes made successfully 50
      3.4.2.1.2 Changes not made or made unsuccessfully 50
      3.4.2.1.3 Wrong ideas and attitudes 51
    3.4.2.2 The Lingering Concept of the Great American Desert Fragmented the Region and Made Coordination Difficult 51

Page

3.4.2.3 A Conflict of Cultures Occurred Between the Plains and the More Humid Prairies, Between the Ranching and Farming Areas 52
3.5 Conservation and Technology, 1946-1972 52
3.6 Inflation, Drought and Uncertainty, 1973-1980 55

4. RESOURCES AND USES 57

4.1 The Ecosystem Concept 57
4.2 Location, Extent and Ownership of the Rangelands of the Great Plains 57
4.3 The Condition of Great Plains Rangelands 63
    4.3.1 Range Condition 63
    4.3.2 Herbage and Browse Production 63
    4.3.3 Brush Infestation 70
    4.3.4 Soil Erosion 70
4.4 Rangeland Uses 70
    4.4.1 Overview of Uses 70
    4.4.2 Minerals 79
    4.4.3 Water Resources 79
    4.4.4 Forage for the Grazing Food Web 91
    4.4.5 Use of Range Vegetation for Fuel Production 98
    4.4.6 Recreation 98
    4.4.7 Research and Education 100
4.5 Compatibility of Uses 106

5. RANGELAND DETERIORATION AND IMPROVEMENT 108

5.1 Rangeland Deterioration 108
    5.1.1 Agents of Deterioration 108
    5.1.2 The Interacting Causes 111
        5.1.2.1 Stressors 111
        5.1.2.2 Basic Requirements 111
        5.1.2.3 Factors Predisposing to Range Deterioration 113
            5.1.2.3.1 Economic factors 113
            5.1.2.3.2 Speculative opportunity 113
            5.1.2.3.3 Judgment factors 114
    5.1.3 Patterns of Deterioration 115
    5.1.4 Extent of Deterioration 115
    5.1.5 Results of Rangeland Deterioration 115
5.2 Rangeland Improvement 122
    5.2.1 Goals and Objectives 122
    5.2.2 Inventory, Assessment, and Problem Definition 122
    5.2.3 Formulation of Alternatives 124
    5.2.4 Available Range Improvement Practices 124
    5.2.5 Selection of Optimum Alternatives 125
        5.2.5.1 Basic Information 125

Page

5.2.5.2 Computational Devices 150
5.2.5.3 Mathematical Models and Procedures 151

6. RANCHING, KINDS OF LAND, AND LAND CONVERSIONS 153

6.1 Kinds of Businesses Using Rangelands 153
6.2 Global and National Trends Affecting Businesses Using Great Plains Rangelands 155
6.2.1 Population 155
6.2.2 Gross National Product per Capita 160
6.2.3 Effect of Growth of Population and Gross National Product per Capita 160
6.2.3.1 Food and Fiber 160
6.2.3.2 Land Deterioration 169
6.2.3.3 Exhaustion of Resources 174
6.2.3.4 Pollution 174
6.2.3.5 Possible Climatic Changes 177
6.2.3.6 Growth of Technology 181
6.2.3.7 Summary Statement 181
6.3 Financial Status and Problems of Ranches on the Great Plains 182
6.4 Land Conversions 195
6.5 Optimum Combination of Rangeland, Introduced Pasture and Cropland 203
6.6 Some Alternatives for Increasing Net Ranch Income 208
6.6.1 General Remarks 208
6.6.2 Minimum Use of Cultural Energy in Meat Production 208
6.6.2.1 Role of Ruminants 208
6.6.2.2 Beef Production 210
6.6.2.3 Combinations of Grazing Animals 219
6.6.3 Diversification of Sources of Income to Maximize Flexibility 223
6.7 Use of Leased Lands 224

7. SOCIAL ACTION 225

7.1 Introductory Statement 225
7.2 Education 226
7.2.1 Introductory Statement 226
7.2.2 University Education 227
7.2.3 Primary and Secondary Education 228
7.2.4 Vocational and Technical Schools 230
7.2.5 Adult Education 230
7.2.5.1 Agricultural Extension Service 230
7.2.5.2 Other Agencies 231
7.2.5.3 Society for Range Management 231
7.2.5.4 Other Private Organizations 232
7.2.6 Summary 232
7.3 Technical and Financial Assistance 233
7.4 Federal Rangeland Policies 236

Page

7.4.1 Present Federal Policies 236
  7.4.1.1 Background 236
  7.4.1.2 Recent Policy Statements 240
7.4.2 Major Problems of Rangelands in Relation to Policy 242
  7.4.2.1 General 242
  7.4.2.2 Overgrazing 242
  7.4.2.3 Below-Optimum Production 243
  7.4.2.4 Cultivation of Land That Should be Rangeland 244
  7.4.2.5 Impacts of Mineral Development 244
  7.4.2.6 Supply of Professional Range-Educated Personnel 244
7.4.3 Philosophy of Government 245
  7.4.3.1 The Traditional Philosophy 245
  7.4.3.2 The Social Democratic Philosophy 246
  7.4.3.3 Comparison 247
7.4.4 Needed Changes in Policies or Directives 248
  7.4.4.1 Equality of Rangeland With Cropland and Forestland 248
  7.4.4.2 Organization and Personnel 248
  7.4.4.3 Data Base 249
  7.4.4.4 Planning and Administration of Public Lands 250
  7.4.4.5 Education, Technical and Financial Assistance 251
  7.4.4.6 Cultivated Land Unsuitable for Crop Production 253
  7.4.4.7 Education of the General Public 254
  7.4.4.8 Matters Relating to Fiscal and Monetary Policy 255
  7.4.4.9 Federal versus Regional or State Control 256
7.5 Range Research 258

8. GLOSSARY 271

LITERATURE CITED 279

LIST OF TABLES

Table		Page
1	Soil Orders and Suborders Occurring Within the Great Plains Region with a Brief Description of Each	6
2	Distribution of Precipitation (April through August) by Groups of Years, Miles City, Montana, 1878-1946	26
3	Predicted Effect of Global Warming Due to Increased Atmospheric CO_2 on Temperature, Precipitation and Water Relations of Rangelands of the Central Great Plains of Northeastern Colorado	30
4	Characteristics of Productivity Classes Within Ecosystems in the Great Plains Region	36
5	Structure and Function of Range Ecosystems in the Great Plains	59
6	Rangeland Area by States and by Ecosystems	61
7	Rangelands of the Great Plains Region by Ecosystem and Ownership, 1970	62
8	Range Condition Class by Ecosystem	64
9	Range Condition Class by States in the Great Plains	65
10	Change in Range Condition of Nonfederal Rangeland in the Great Plains From 1963 to 1977	66
11	Average Annual Herbage and Browse Production and Area by Productivity Class of Range Ecosystems	67
12	Acreage of Brush, Percentage of Area of Brush in Different Density Classes, Percentage Change in Density 1963-73, and Percentage Grazing Land Covered by Brush in the Great Plains States	71
13	Resources and Uses of Range Ecosystems of the Great Plains	75
14	Inland Water Surface Areas in the Great Plains States	85
15	Water Resource Subregions of the Great Plains with Consumptive Water Use Exceeding 50% of the Water Supply Which is Available Without Ground Water Mining 90% of the Time	93

Table		Page
16	Fresh Water Withdrawal and Consumption by Various Uses by Water Resource Region, 1975 With Projection to 2030	95
17	Grazing Available by Ecosystem and Management Level, 1976	96
18	The National Wilderness Preservation System in the Great Plains	105
19	Compatibility of Important Uses at the Same Place or in the Same Vicinity in the Great Plains	109
20	Effects of Grazing During the Growing Season by Different Groups of Species at Different Management Levels on Selected Properties of Range Ecosystems of the Great Plains	116
21	Evaluation of Practices for Manipulating the Grazing Food Web in Range Ecosystems of the Great Plains	126
22	Evaluation of Practices for Manipulating the Vegetation in Range Ecosystems of the Great Plains	133
23	Evaluation of Practices for Manipulating Site Constants and Driving Variables in Range Ecosystems of the Great Plains	138
24	Facilities and Equipment for Managing and Improving Range Ecosystems of the Great Plains	143
25	Classes of Chemicals for Managing and Improving Range Ecosystems on the Great Plains	149
26	Commercial Farms by Enterprise by Size, Kind of Land, Proportion of Beef Cattle and Size Group of Beef Cattle for Northern and Southern Plains States, 1969 Census	154
27	Bureau of Census Estimates and Projections, Medium Series, Summary Data, 1975-2000	156
28	Census Bureau Annual Decline in Crude Birth Rate	159
29	Gross National Product per Capita (1975) With Predictions for 1985 and 2000 for More Developed and Less Developed Countries and the United States	161
30	Grain and Meat Consumption per Capita, 1970 with Projections	163

Table		Page
31	Projections of Grain Production, Consumption and Trade by Region	164
32	Number of Cattle and Number of Sheep and Goats, 1955-2000	171
33	Winrock Projections of World Feed Resources for Ruminants	172
34	Winrock Projections of World Ruminant Populations	172
35	Life Expectancies of 1976 World Reserves of Selected Mineral Commodities at Two Different Rates of Demand	175
36	Five Global Scenarios of Future Climates with Estimates of Their Probability and the Probability of Three Precipitation Patterns in Various Areas of the World in the 1990s	180
37	Management Considerations for the Land Subsystem of the Ranch Ecosystem with Special Reference to Range	184
38	Management Considerations for the Livestock Subsystem for the Ranch Ecosystem	185
39	Management Considerations for the Management Subsystem of the Ranch Ecosystem	187
40	Efficiency Measures of Typical Cow-calf Ranches, Selected Areas of the Great Plains	189
41	Net Ranch Income of Medium-sized Ranches in the Plains Area of Northeastern New Mexico as Related to Cattle Prices and Precipitation	190
42	Changes in Number and Cost of Rangeland Facilities from 1965-1977 in Northeastern New Mexico on Medium-sized Cow-calf Ranches	190
43	Financial Summary of Great Plains Ranches in Northeastern New Mexico by Size, 1977	192
44	Change in Area of Non-federal Rangeland in the States Containing the Great Plains from 1967 to 1977	197
45	Land Use Conversion in South Dakota, 1967-1980	199

Table Page

46 Land Use Conversion in South Dakota by Land Capability, 1967-1975 as Percentage of Rural, Non-federal Land 200

47 Cropland and Rangeland-to-Cropland Conversion by Land Capability in South Dakota 1967 to 1980, as Percentage of Rural, Non-federal Land 202

48 Generalized Beef Production Data and Economic Returns from Four Grazing Systems, 1966-72 205

49 Examples of Methods for Increasing Livestock Numbers on Great Plains Grasslands, Based on Data from Grazing Investigations at the Northern Great Plains Research Center, Mandan, North Dakota 207

50 Efficiency of Meat Production by Different Animal Species Fed Rations for Optimum Production 209

51 Efficiency of Food Production in Terms of Cultural Energy Expended 209

52 Efficiency of Meat Production, Cow-Calf Operation, Eastern Colorado Experiment Station, 1971-74 211

53 Efficiency of Meat Production from Four Linear Programming Solutions, Eastern Colorado Experiment Station 213

54 Efficiency of Meat Production from Typical Livestock Operations 214

55 Results of Goal Programming with Highest Priority Goal Changing 216

56 Results of Goal Programming with Meat Production as Highest Priority Goal, Fossil Fuel Conservation Second, and Profit Third with Different Levels of the Meat Production Goal 218

57 Efficiency of Fiber Production 221

58 Average Productive Efficiency for Cattle, Sheep and Rabbits When Supported Entirely on Rangelands on a Sustained Yield Basis 222

Table Page

59 Cost-Sharing Activities of the Agricultural Conservation Program in the Great Plains States, 1978 234

60 Summary of Inventory and Recommendations 260

61 Summary of 1967, 1975, and Future Recommended Allocation of Scientist Year (SY's) to Range and Forage Research by Research Problem Areas (RPA's) 262

62 Summary Table Showing Allocation of Scientist Years (SY's) to Research Problem Areas (RPA's) Under Different Levels of Funding 263

63 Problem Categories and Research Priorities for Western Ranges 264

64 Herbage Consumption and Wastage by Major Herbivores, Mixed Prairie, Cottonwood, South Dakota, 1972 269

LIST OF FIGURES

Figure Page

1 Physiographic provinces of the United States (227, p. 8) 3

2 Parent materials of the soils of the United States (227, p. 126-217) 4

3 Generalized soil map of the United States (228, p. 412) 5

4 Average freeze-free period, 1921-50 (231, p. 247) 8

5 Average potential evapotranspiration (234, p. 64) 9

6 Correspondence of climate and biota in eastern North America north of Mexico (231, p. 20) 10

7 Average number of months per year with a mean transport of air from the eastern base of the Rocky Mountains (232, p. 12) 12

8 Mean annual total precipitation, based on all available stations adjusted to standard period 1931-1960 (231, p. 210) 13

9 Thornthwaite-Mather model for energy balance and water balance (236, 235, p. 24) 14

10 Components of the normal water balance calculated by months using the method of Thornthwaite and Mather (236, 237, p. 321) 15

11 North American IBP Grassland sites (past, present, and proposed) (238, p. 3) 16

12 Soil water storage (W_2) at different Grassland Biome sites based on long-term average data (235, p. 31) 17

13 Available soil water (about 1970 field minimum) measured and predicted from estimates of soil water calculated by the method of Thornthwaite and Mather (236), Grassland Biome, 1970 (237, p. 330) 18

14 Months of dominant concentration of precipitation (231, p. 218 from 239) 19

Figure Page

15 Location of axis of low-level jet in 26 of 28 cases, 1959-1960 (231, p. 196) 21

16 The boundary between the dry and humid climates in the Great Plains (304, p. 14) 22

17 The fluctuating semi-arid subhumid boundary for the Great Plains over the years 1923-1927 (305, p. 44 from 337) 23

18 The distribution of COEFVS (Coefficient of Variability Sequence, a Measure of Clumping) of annual precipitation (306, p. 41) 24

19 Total annual precipitation at Pierre, South Dakota, 1893-1972, showing deviations from the median (307, p. B-17) 25

20 Sunspot cycles (a), double sunspot cycles (b), and coincidence of double sunspot cycles and major drought periods in Nebraska (c) (333, p. 88-89) 29

21 Generalized classification of the vegetation of the central United States grasslands according to various authors (364, p. 133) 32

22 Forest and range ecosystems of the United States, 1977 (371, p. 33

23 Explorations in the Great Plains before 1800 (291, p. 44) 39

24 Expeditions into the Great Plains, 1803-46 (291, p. 58) 41

25 The Louisiana Purchase, 1803, and the Texas Annexation, 1845 (291, p. 57) 43

26 Nineteenth-century avenues of travel across the Great Plains (291, p. 90) 44

27 Cattle trails (291, p. 106) 46

28 Sheep trails (291, p. 120) 47

29 Institutions of higher education in, and within a hundred miles of, the Great Plains (291, p. 218) 53

Figure Page

30 Flow chart for a land ecosystem showing site constants, driving variables, driven abiotic variables, vegetation, grazing food web, and inputs from other ecosystems (307, p. B-13) 58

31 Diagram of energy flow through the producer system of the mixed-grass prairie ecosystem (Dickinson, Cottonwood and Hays sites) during the growing season (219, p. 997) 68

32 Diagram of energy flow through the producer system of the tallgrass prairie ecosystem (Osage site) during the growing season (219, p. 998) 69

33 Diagram of energy flow through the producer system of the shortgrass prairie ecosystem (Pawnee and Pantex sites) during the growing season (219, p. 998) 69

34 Brush distribution and density (383, p. 3-51) 72

35 Trend in density and acres of brush on nonfederal rangeland, native pasture, and pastureland (383, p. 3-59) 73

36 Sheet and rill erosion on nonfederal rangeland (383, p. 3-47) 74

37 Geographic distribution of metallic minerals with respect to federally-owned lands (226, p. 74) 80

38 Strippable coal reserves of the conterminous United States, by region (383, p. 3-97) 81

39 Geographic distribution of coal, oil shale, and tar sands with respect to federally owned lands (226, p. 78) 82

40 Oil shale deposits (382, p. 45) 83

41 Water resource regions and subregions (226, p. 432) 84

42 Percentage of streams having limited water quality (383, p. 5-28) 86

43 Location of severe livestock watering problems (383, p. 5-47) 87

44 Total acreage in wetland types 3-20, by ASA (389, p. 3-21) 88

Figure Page

45 Average distribution of North American breeding and wintering ducks (382, p. 99) 89

46 Status of wetlands in the United States (226, p. 219) 90

47 Major areas of potential groundwater development (226, p. 455) 92

48 Areas of ground water mining, 1975 (383, p. 5-8) 94

49 Grazing by kind of livestock (226, p. 281) 97

50 National park system (382, p. 38) 101

51 National wildlife refuges (382, p. 34) 102

52 Present wilderness system (382, p. 41) 103

53 Wilderness review and study areas (382, p. 80) 104

54 Principal prairie areas of the Nature Conservancy (397, p. 15) 107

55 Twenty-five years of world population growth, medium series (455, p. 13) 157

56 Age-sex composition of population, medium series, 1975 and 2000 (455, p. 17) 158

57 World grain yields, actual and projected under Alternatives I, II, III (455, p. 76) 165

58 Arable land per capita, 1955, 1975, and 2000 (455, p. 403) 166

59 Energy intensity data (455, p. 86) 167

60 Energy used in agriculture, 1974 (455, p. 87) 168

61 Energy used in agriculture, plus fertilizer and chemicals, 1974 (455, p. 87) 168

62 Energy flow in the U.S. food chain, in billions of joules (455, p. 295) 170

63 Desertification map (455, p. 278) 173

64 World maximum oil production at a medium depletion rate and world demand at three growth rates of oil production (455, p. 177) 176

Figure Page

65 Trend since 1958 in the concentration of carbon dioxide in the atmosphere (parts per million by volume), as monitored at the National Oceanic and Atmospheric Administration's Mauna Loa Observatory, Hawaii, 19.5° N latitude, 3,401 meters altitude (455, p. 258) 178

66 Carbon dioxide concentrations implied by various energy scenarios (455, p. 262) 179

67 Flow chart for a ranch ecosystem showing the relationship with national and world ecosystems and the relationships of the land, livestock and management subsystems within the ranch ecosystem (307, p. B-11) 183

68 Purchasing power of money (451, p. 1) 191

69 Interest rates and inflation (451, p. 6) 191

70 Land use conversions between 1967 and 1975 (millions of acres) (383, p. 2-9) 196

71 Projected changes in cropland acreage for the year 2030, by producing area (millions of acres) (383, p. 5-11) 201

72 Cultural energy use for various options and phases of the beef production system in Colorado (440, p. 269) 215

73 Net primary production and the partitioning of energy flow in three grasslands without large herbivores, 1972 (29) 267

74 Partitioning of herbivore consumption and wastage in three grasslands without large herbivores, 1972 (29) 268

Background Paper No. 19

IMPACTS OF TECHNOLOGIES ON PRODUCTIVITY AND QUALITY OF RANGELANDS IN THE GREAT PLAINS REGION[1]

James K. Lewis and David M. Engle[2]

1. INTRODUCTION

The Great Plains region was settled and developed into a great ranching and farming region by the use of technology. By the use and misuse of technology, ranges have been depleted, fertile lands laid bare to erosion and land owners driven to bankruptcy. With the use of technology, ranges have been restored, the ravages of erosion healed and prosperity restored to the land. In this report technology is considered as the sum total of applied knowledge from various disciplines in the form of technical expertise, equipment and facilities which impact the rangelands of the Great Plains. Technology can be beneficial or detrimental.

Range science is the constantly growing, organized body of knowledge that undergirds the practice of range management and provides for the development and wise use of technology in the management of ranges. Productivity is considered to be the state of being productive of quantity of goods and services for the satisfaction of human wants. Quality is considered to be the degree of excellence with which the wide range of human wants are satisfied. Rangelands are lands on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs or shrubs suitable for grazing or browsing use, including lands revegetated naturally or artificially to provide a forage cover that is managed like native vegetation (224). The Great Plains Region of the United States is considered to extend from Canada to Mexico, from the Front Range of the Rocky Mountains on the west to the margin of the forest on the east and is also synonymous with the Great Plains Ecogroup of the Forest-Range Environmental Study (225). It is composed of the Plains grasslands, Prairie, Shinnery and Texas savanna ecosystems as defined by the Forest Service in the 1980 RPA (226). Definitions of various technical terms are given in the glossary (section 8, page 271).

---

[1] Working paper developed at the request of the Congress of the United States, Office of Technology Assessment, under order number 031-0372.

[2] Associate Professor and Assistant Professor, Department of Animal Science (Range Scientists), South Dakota State University, Brookings, South Dakota 57007.

2. GENERAL DESCRIPTION

2.1 Geology and Soils

The Great Plains is a vast alluvial plain extending from the base of the Rocky Mountains to the Central Lowland and from the Balcones Escarpment in the south to the McKenzie River delta of the north. The plain slopes eastward at the rate of about 10 feet per mile in the United States.

The Great Plains Region as defined in section 1 includes the Great Plains physiographic province, extensive portions of the Central Lowland and part of the Coastal Plain in Texas and Oklahoma (Fig. 1, 227).

Parent materials are extremely diverse ranging from glacial drift to sedimentary deposits to wind-blown sand (Fig. 2, 227). A generalized soils map of the United States is shown in Fig. 3 (228) with a description of major soil groups in Table 1 (adapted from 229). A more detailed map of the Great Plains has been prepared by Aandahl (372). Detailed soil surveys are available for most of the counties of the region from the state offices of the Soil Conservation Service.

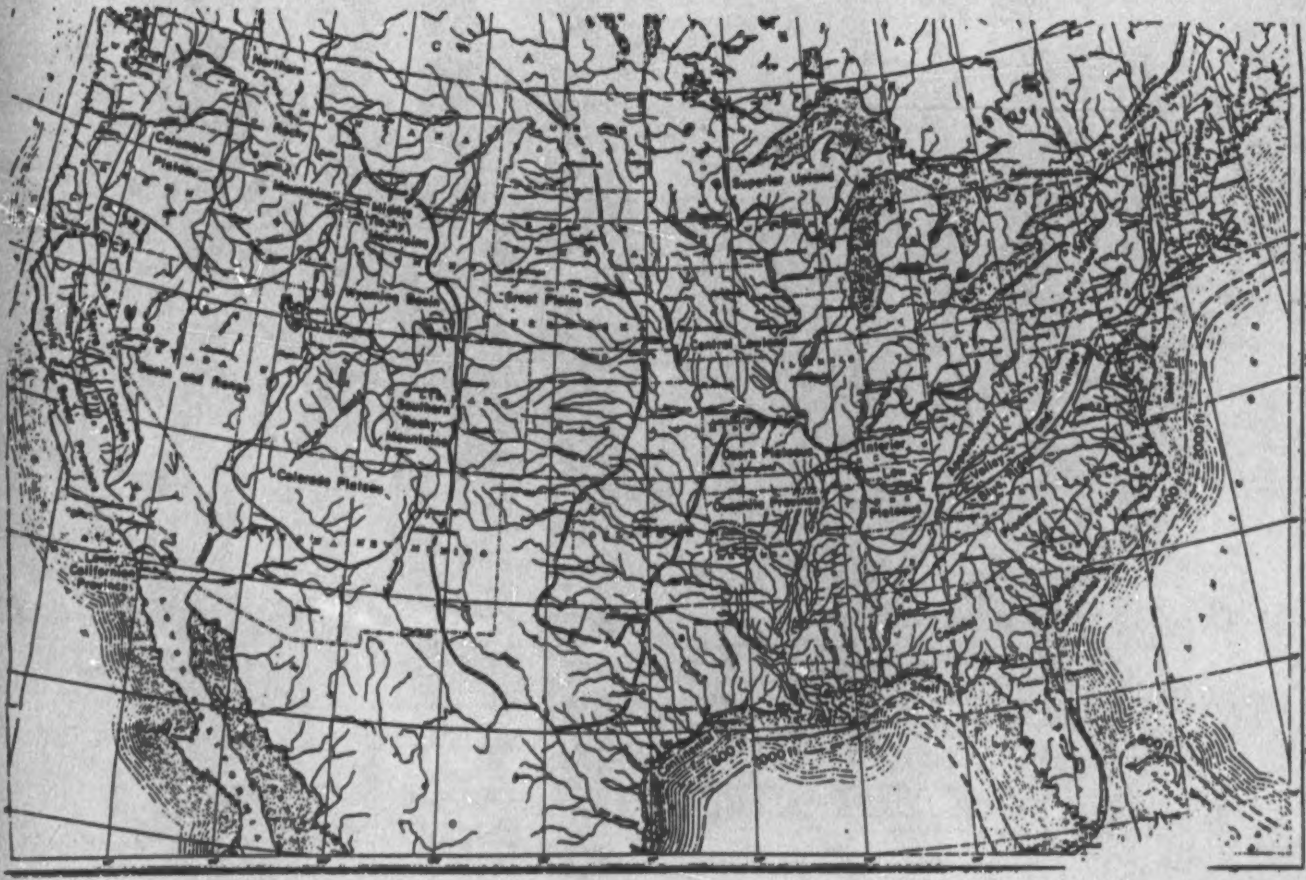

Northern Rocky
Columbia Plateau
Middle Rocky Mountains
Wyoming Basin
Great Plains
Superior Upland
Central Lowland
Basin and Range
Southern Rocky Mountains
Colorado Plateau
Ozark Plateau
Ouachita Province
Interior Low Plateaus
Lower Californian Province
500 ft
2000 ft
Shelf

Figure 1. Physiographic provinces of the United States (227). The rangelands of the Great Plains occupy the Great Plains portions of the Central Lowlands and Coastal Plain.

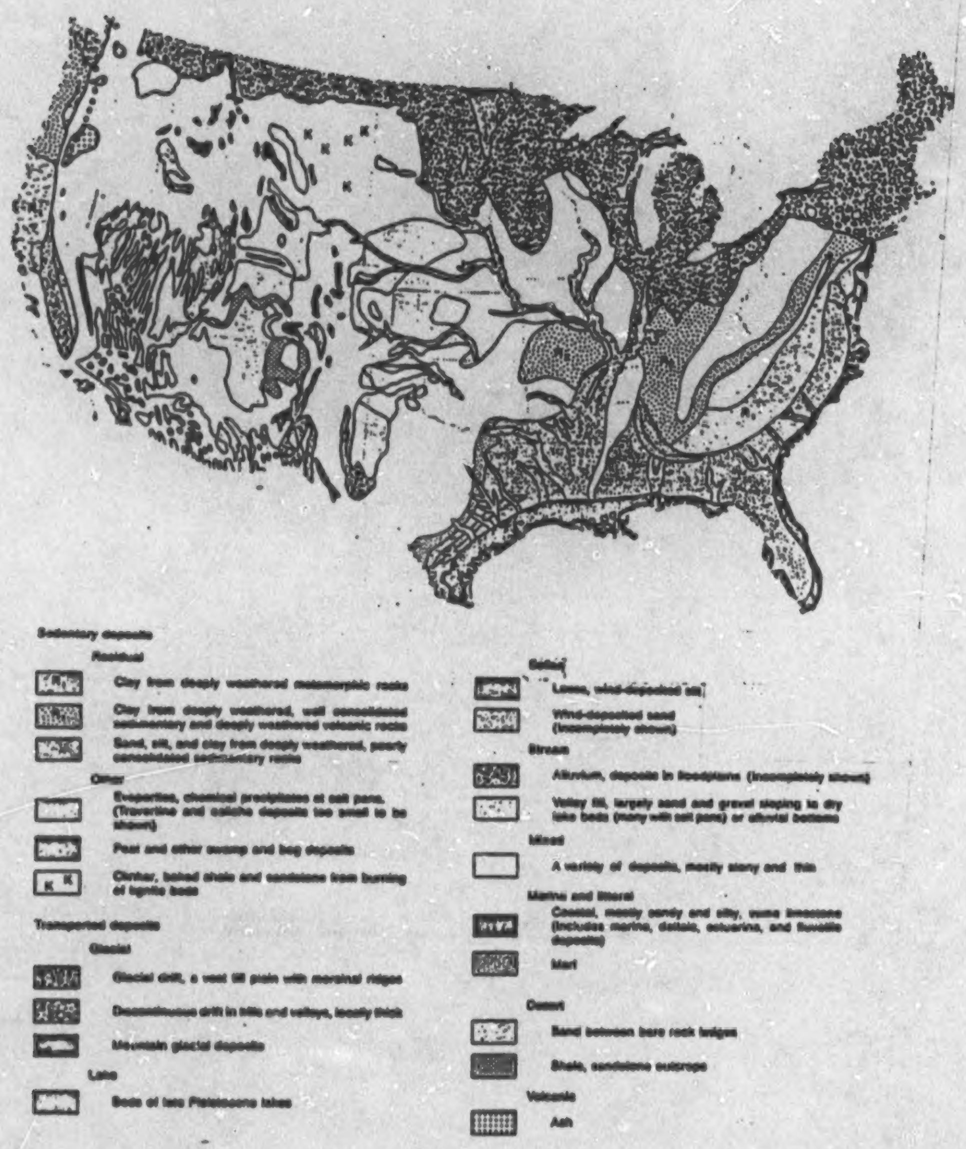

Sedentary deposits
Residual
Clay from deeply weathered metamorphic rocks
Clay from deeply weathered, well consolidated sedimentary and deeply weathered volcanic rocks
Sand, silt, and clay from deeply weathered, poorly consolidated sedimentary rocks
Other
Evaporites, chemical precipitates at salt pans. (Travertine and caliche deposits too small to be shown)
Peat and other swamp and bog deposits
Clinker, baked shale and sandstone from burning of lignite beds
Transported deposits
Glacial
Glacial drift, a vast till plain with morainal ridges
Discontinuous drift in hills and valleys, locally thick
Mountain glacial deposits
Lake
Beds of late Pleistocene lakes
Eolian
Loess, wind-deposited silt
Wind-deposited sand (incompletely shown)
Stream
Alluvium, deposits in floodplains (incompletely shown)
Valley fill, largely sand and gravel sloping to dry lake beds (many with salt pans) or alluvial bottoms
Mixed
A variety of deposits, mostly stony and thin
Marine and littoral
Coastal, mostly sandy and silty, some limestone (includes marine, deltaic, estuarine, and fluvatile deposits)
Marl
Desert
Sand between bare rock ledges
Shale, sandstone outcrops
Volcanic
Ash

Figure 2. Parent materials of the soils of the United States (227).

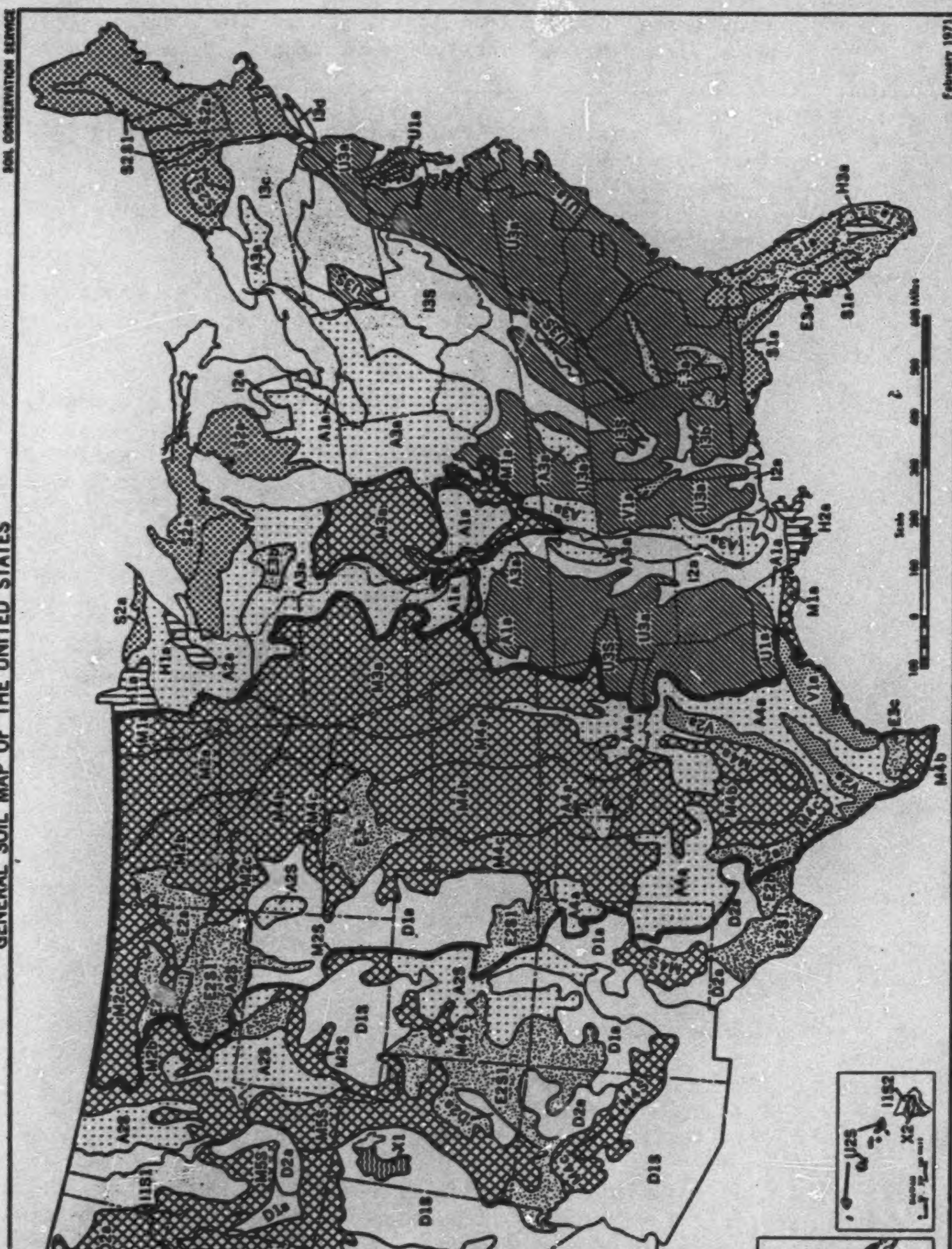

GENERAL SOIL MAP OF THE UNITED STATES
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
February 1971

Figure 3. Generalized soil map of the United States (228). Major soil orders and suborders occurring within the Great Plains Region are outlined in red. Map symbol descriptions are given in Table 1.

Table 1. Soil Orders and Suborders Occurring Within the Great Plains Region with a Brief Description of Each (229)

Mollisols:	Soils with almost black, high organic matter and base-saturated surface horizons
M1	Aquolls: (seasonally water saturated) gently sloping; mostly drained and cropped (Humic Gley soils)
M2	Borolls: (cool or cold) gently or moderately sloping; mostly cropland (some Chernozem soils)
M3	Udolls: (temperate or warm, and moist climates) gently or moderately sloping; mostly cropland (some Brunizem soils)
M4	Ustolls: (dry soils with spring or summer rains) gently to moderately sloping; mostly native range in western part and cropped in eastern part (Chestnut soils and some Chernozems and Brown soils)
Entisols:	Soils without natural genetic horizons
E2	Orthents: (loamy or clayey textures) deep to hard rock; gently to moderately sloping; mostly range with some irrigated cropland (Regosols)
E2S	Orthents: shallow to bed rock; steep; mostly range (Lithosols)
E3	Psamments: (sand or loamy sand textures) gently to moderately sloping; mostly range (Regosols)
Alfisols:	Soils with gray to brown surface horizons, medium to high base status, and accumulations of clay in the subsoil
A2S	Boralfs: steep; forest, open forest, and savannah (range)
A4	Ustalfs: (warm with intermittent long dry periods) gently or moderately sloping; range with large areas of irrigated and dryland cropland (Reddish Chestnut soils)
Aridisols:	Soils with an ochric epipedon and are dry most of the year
D1	Argids: (with a horizon of clay accumulation) gently and moderately sloping; mostly range with some irrigated cropland (Reddish-brown and Brown soils and associated solodized-solonetz soils)
Vertisols:	Soils with high contents of shrink-swell clays that develop deep cracks in some seasons
V2	Usterts: (cracks open and close twice yearly remaining open for more than 3 months; mostly cropland (some Grumusols)

2.2 Climate

2.2.1 Recent Climatic Regime

2.2.1.1 The Average Condition

The Great Plains region extends from about 25° to 49° N. latitude, spanning more than 1600 miles from the lower Rio Grande valley to the Canadian border. The average annual temperature, length of the frost-free season (Fig. 4, 231), and the potential evapotranspiration (Fig. 5, 234) are generally zoned with increasing values from north to south.

In addition to latitude the climate of the region is controlled mainly by the interplay of three air masses: Arctic, Pacific, and Gulf. "Sweeping westward across the warm Caribbean Sea, the northern branch of the Atlantic tradewind circulation curves northward over the Gulf of Mexico and pushes across the low coastline. From central Texas to Iowa and the Great Lakes, the average western margin of this flow creates a major climatic transition zone between the humid southeastern third of the country and the semiarid western plains and plateaus. The grasslands of the Great Plains extend northeastward into the prairies of Iowa and Illinois along the outer flank of this flow of tropical air and south of the main route of Arctic air" (231, p. 195).

During the winter, cold fronts of dry frigid air from the Arctic sweep all the way south into Mexico. The Great Plains lie in the general region of the prevailing westerly winds. Pacific air moving to the east loses most of its moisture as it ascends the slopes of the Sierras and Cascades. As it passes over the Rockies it is supplemented by air entering at higher elevations and descending the eastern slope of the mountains with warming due to adiabatic compression and with decreasing relative humidity. The dry, warm air forms a wedge between the Gulf and the Arctic fronts (Fig. 6, 231). In the drier western region of the Plains (Plains grasslands) the Pacific air covers the land for more than

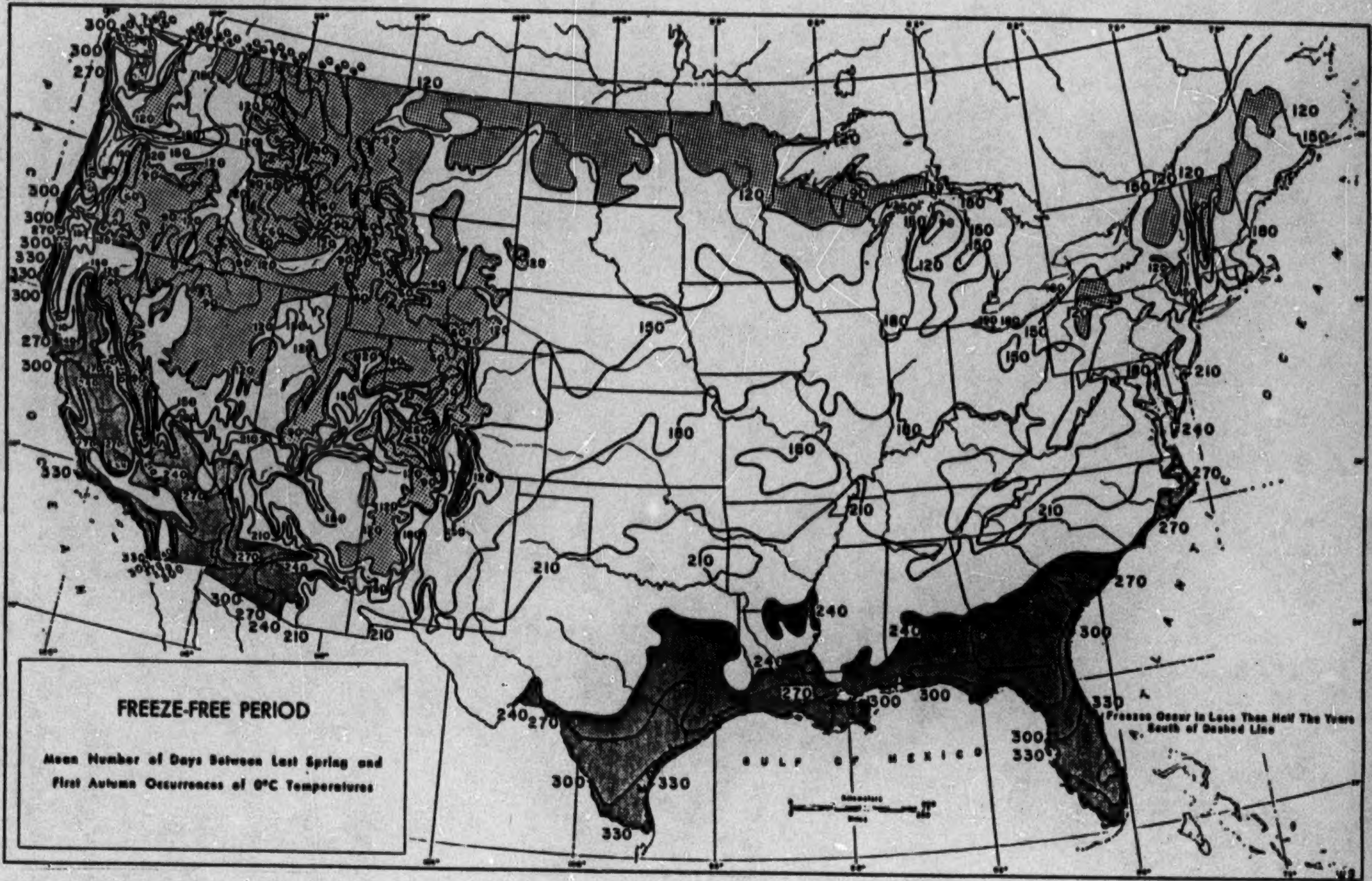

FREEZE-FREE PERIOD
Mean Number of Days Between Last Spring and First Autumn Occurrences of 0°C Temperatures
Freezes Occur in Less Than Half The Years South of Dashed Line
GULF OF MEXICO
120
150
180
210
240
270
300
330

Figure 4. Freeze-free period, 1921-50 (231).

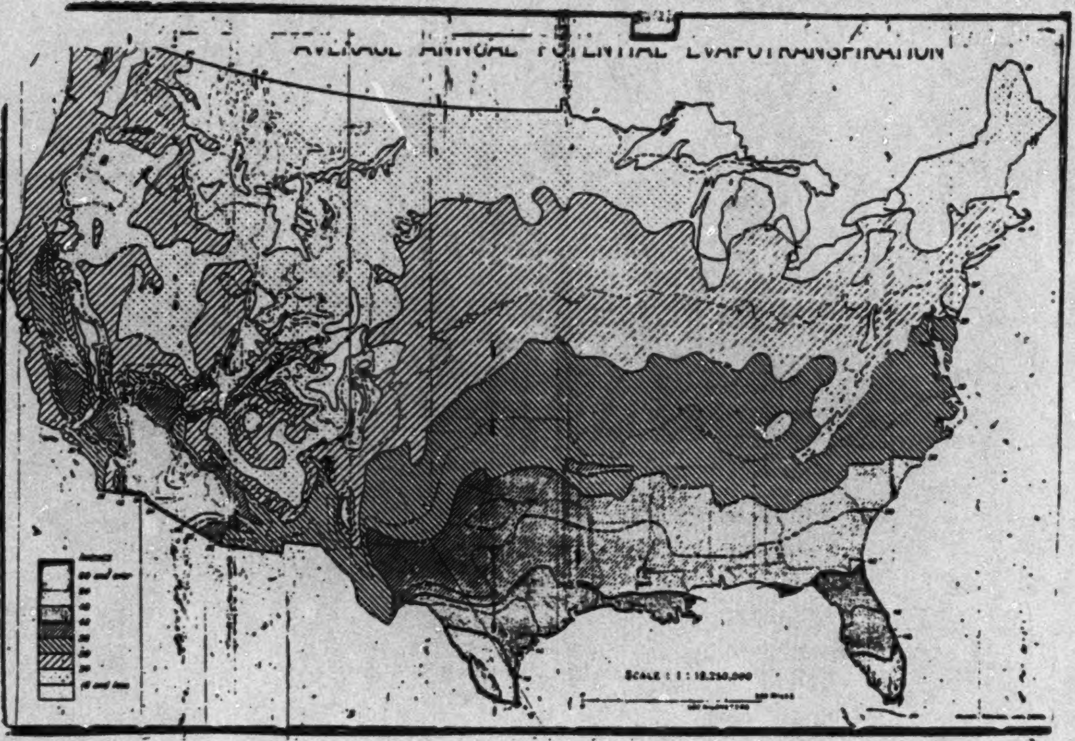

AVERAGE ANNUAL POTENTIAL EVAPOTRANSPIRATION

Figure 5. Average potential evapotranspiration (234).

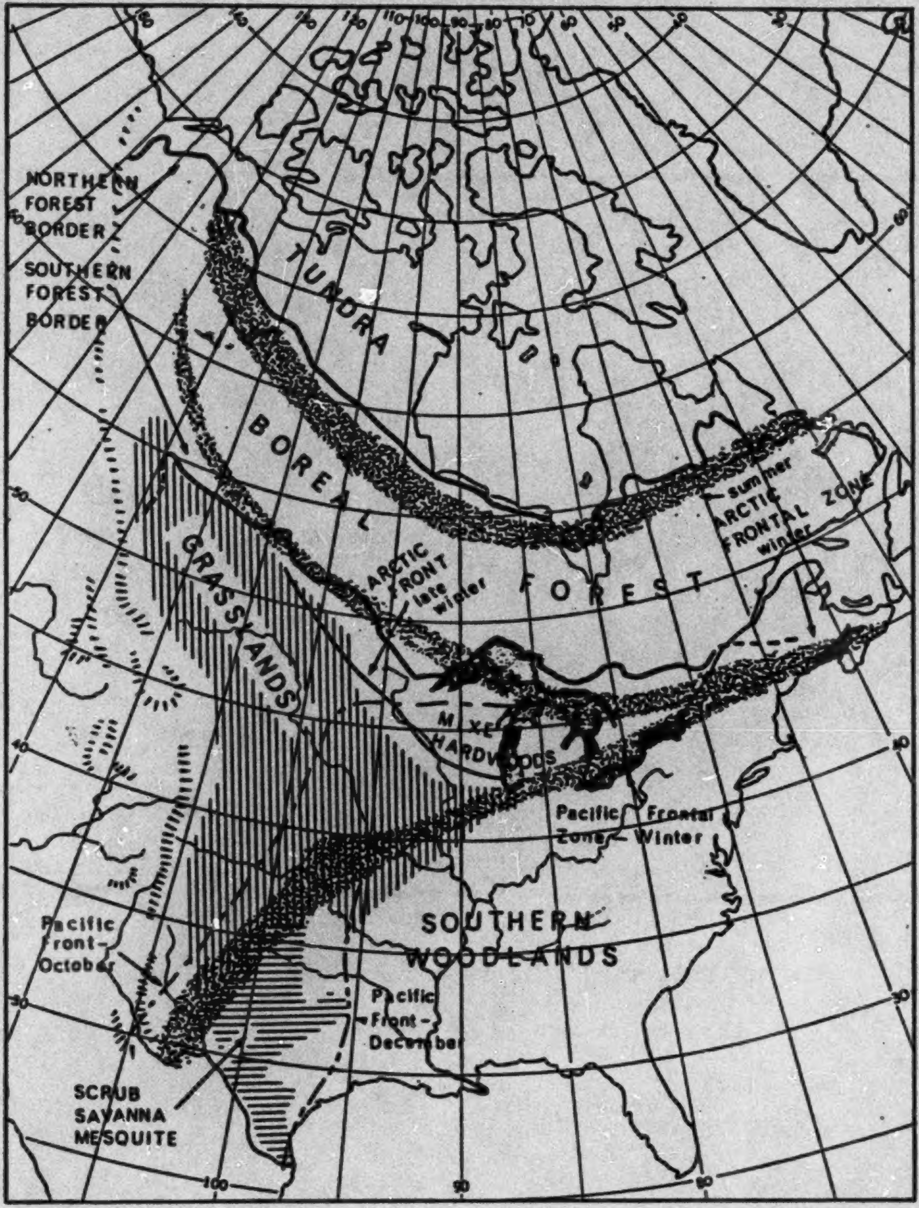

NORTHERN FOREST BORDER
SOUTHERN FOREST BORDER
TUNDRA
BOREAL
FOREST
GRASSLANDS
ARCTIC FRONT late winter
summer
ARCTIC FRONTAL ZONE
winter
MIXED HARDWOODS
Pacific Frontal Zone — Winter
SOUTHERN WOODLANDS
Pacific Front-October
Pacific Front-December
SCRUB SAVANNA MESQUITE
110
100
90
80
70
60
50
40
30

Figure 6. Correspondence of climata and biota in eastern North America north of Mexico (231). Stippled zones indicate selected seasonal airstream boundaries.

half the year, while further east in the Prairie, the dominance of the dry air is reduced to as little as four months by the incursion of moist Gulf air (Fig. 7, 232). This wedge of dry air dominance corresponds closely to the wedge of prairie that extends eastward to Illinois and Indiana (232, 233) and is reflected in dry winters. The average annual precipitation, strongly zoned from about 12 inches in the west to about 40 inches in the southeastern part of the region is deflected eastward along the wedge of westerlies, but indistinctly so (Fig. 8, 231).

The normal water balance, calculated by the Thornthwaite-Mather model (Fig. 9, 235, 236) is shown for experimental locations (Fig. 10, 237) in the Grassland Biome project of the U. S. International Biological Program (Fig. 11, 238). Calculations of water storage from the water balance model for different grasslands are shown in Fig. 12 (235). Agreement between predicted and measured soil water values were quite good in some locations, but not in others, although trends were reliable (Fig. 13, 237). Data on water stress and soil water storage correlated well with plant communities and soils at the study locations.

Seasonal distribution of precipitation through the Great Plains is related to the strong incursion of moist air from the Gulf during the summer. Markham calculated an index of seasonal concentration of precipitation with 0 denoting equal precipitation for each of the 12 months and 100 denoting all of the precipitation falling in one month. Values range from about 20 or less at the forest boundary to over 50 in the Plains grasslands with peak amounts falling in June over most of the area (Fig. 14, 231, 239).

The Great Plains region is generally a region of high wind velocities and violent storms. However, along the margin of the Gulf airstream the Pacific front is a region of a low level jet flowing from SSW to NNE at higher speeds

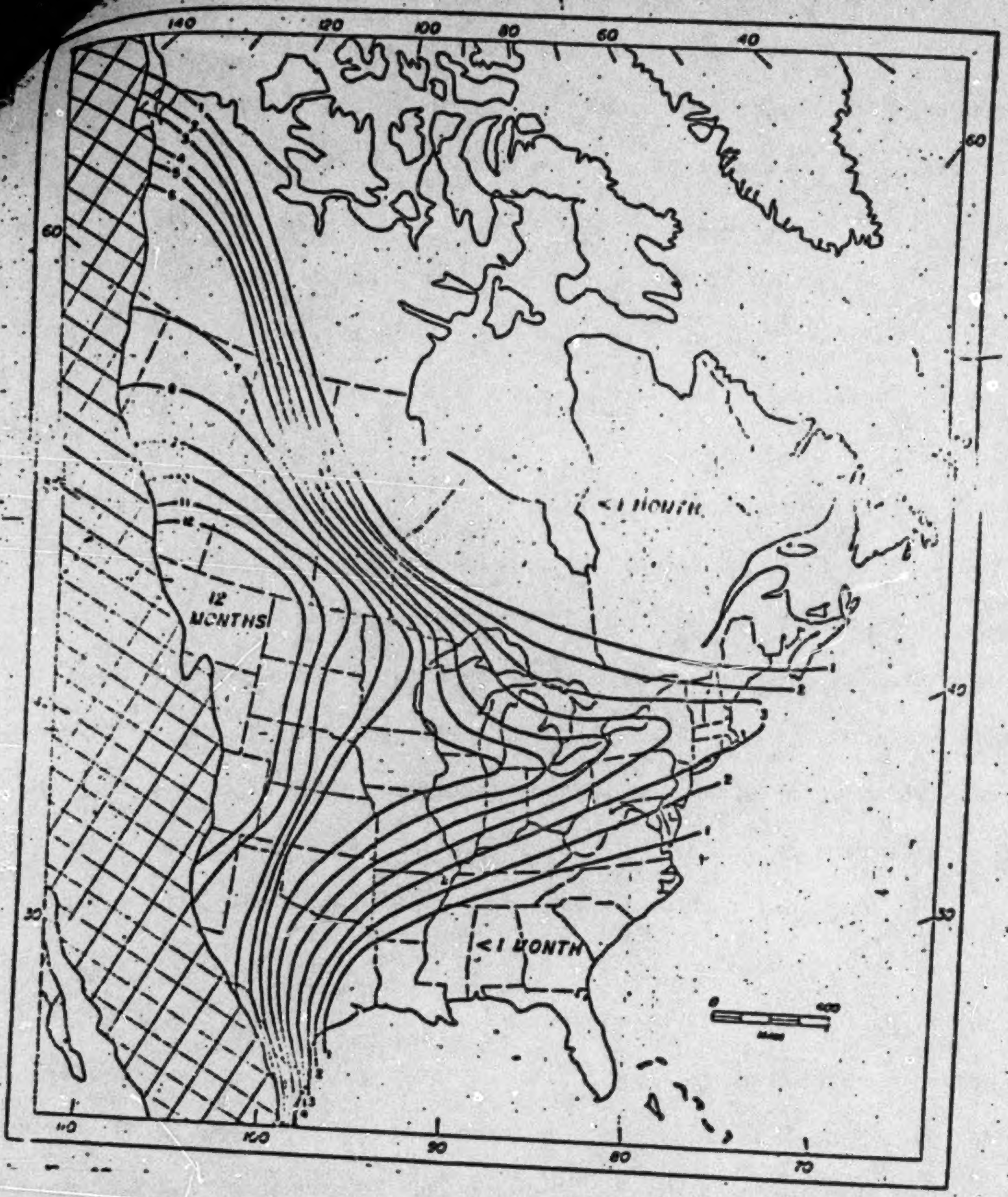

140
120
100
80
60
40
60
60
12 MONTHS
<1 MONTH
<1 MONTH
1
2
3
2
1
40
30
30
0
400
110
100
90
80
70

Figure 7. Average number of months per year with a mean transport of air from the eastern base of the Rocky Mountains (232).

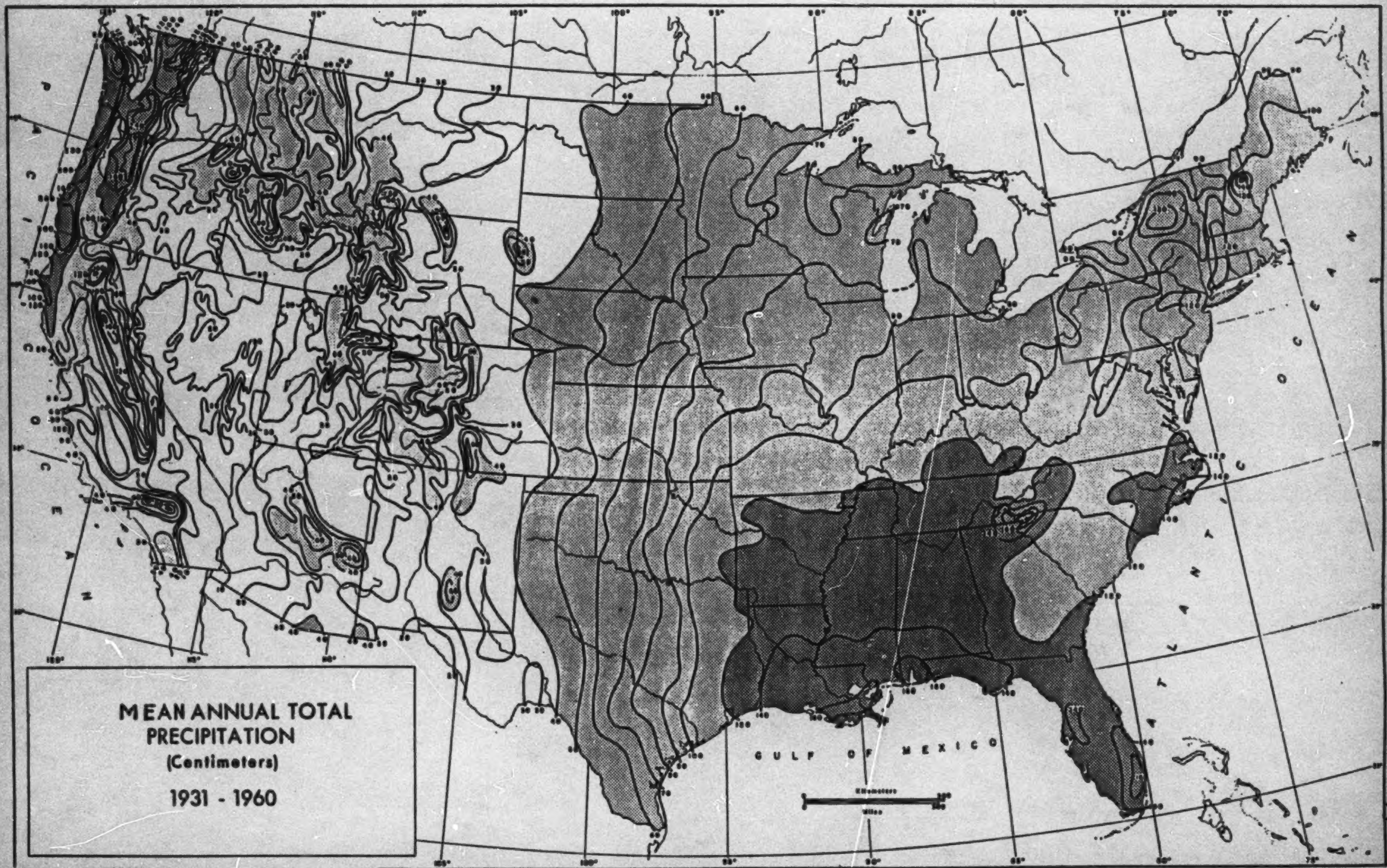
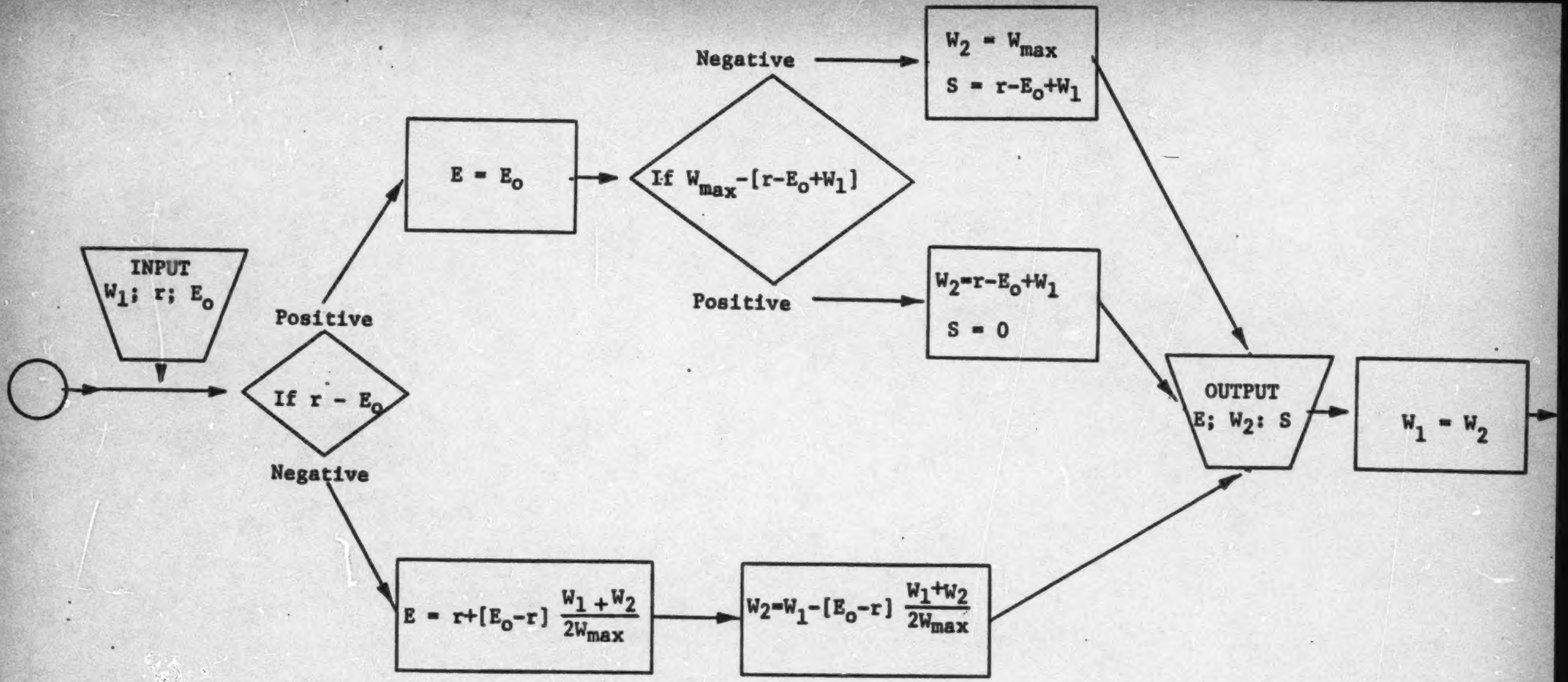

MEAN ANNUAL TOTAL PRECIPITATION
(Centimeters)
1931 - 1960
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
Kilometers
Miles

Figure 8. Mean annual total precipitation, based on all available stations adjusted to standard period 1931-1960 (231).


INPUT
W_1; r; E_o
If r - E_o
Positive
Negative
$E = E_o$
If $W_{max}-[r-E_o+W_1]$
Negative
Positive
$W_2 = W_{max}$
$S = r-E_o+W_1$
$W_2=r-E_o+W_1$
$S = 0$
$E = r+[E_o-r]\ \frac{W_1+W_2}{2W_{max}}$
$W_2=W_1-[E_o-r]\ \frac{W_1+W_2}{2W_{max}}$
OUTPUT
E; W_2: S
$W_1 = W_2$

where:

r = precipitation
E = evapotranspiration
E_o = potential evapotranspiration
S = surplus (runoff)

W_2 = soil water storage at end of period
W_1 = soil water storage at beginning of period.
T = air temperature
ϕ = latitude
W_{max} = maximum possible soil water storage

Figure 9. Thornthwaite-Mather model for energy balance and water balance. Water balance: $r - E = S + W_2 - W_1$. Energy balance: $E_o = f(T,\phi)$ (235, 236).

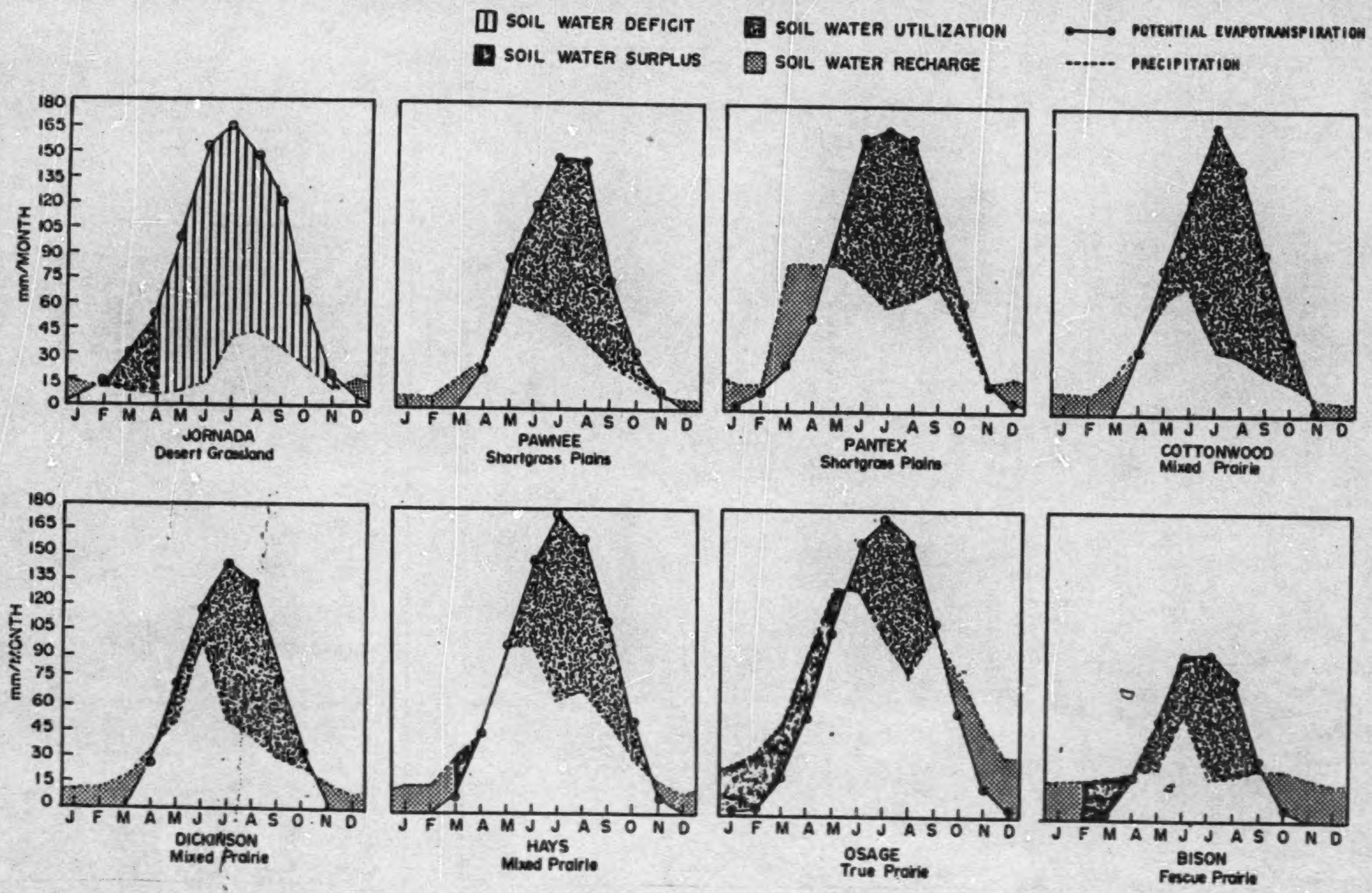
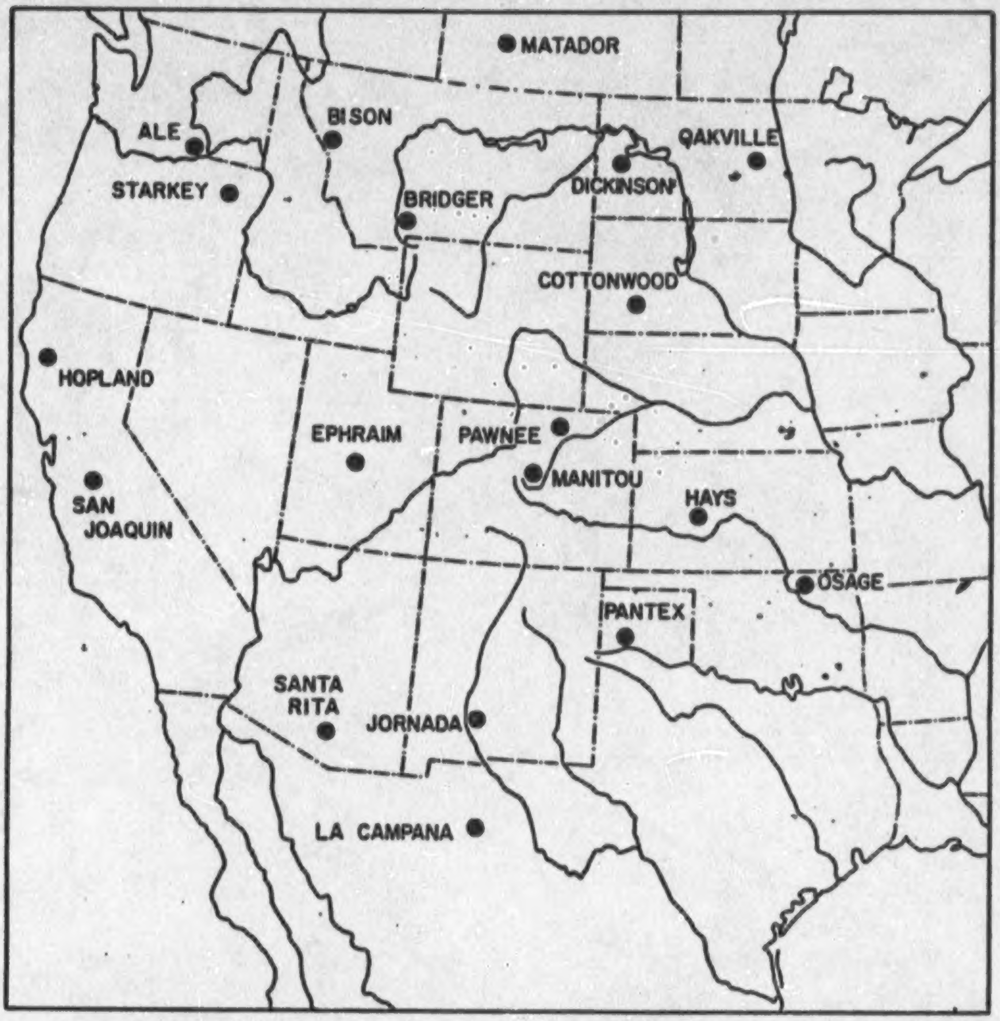


Figure 10. Components of the normal water balance calculated by months using the method of Thornthwaite and Mather (236), Grassland Biome (237).


MATADOR
ALE
BISON
STARKEY
BRIDGER
DICKINSON
OAKVILLE
COTTONWOOD
HOPLAND
EPHRAIM
PAWNEE
MANITOU
SAN JOAQUIN
HAYS
OSAGE
PANTEX
SANTA RITA
JORNADA
LA CAMPANA

SITE	TYPE	SITE	TYPE
● HOPLAND SAN JOAQUIN	ANNUAL GRASSLAND	● MATADOR COTTONWOOD DICKINSON HAYS	MIXED PRAIRIE
● BISON ALE	NORTHWEST BUNCHGRASS	● OSAGE OAKVILLE	TRUE PRAIRIE
● BRIDGER EPHRAIM	HIGH MOUNTAIN	● PAWNEE PANTEX	SHORTGRASS
● MANITOU STARKEY	LOW MOUNTAIN	● JORNADA SANTA RITA LA CAMPANA	DESERT GRASSLAND

Figure 11. North American IBP Grassland sites (past, present, and proposed) (238).

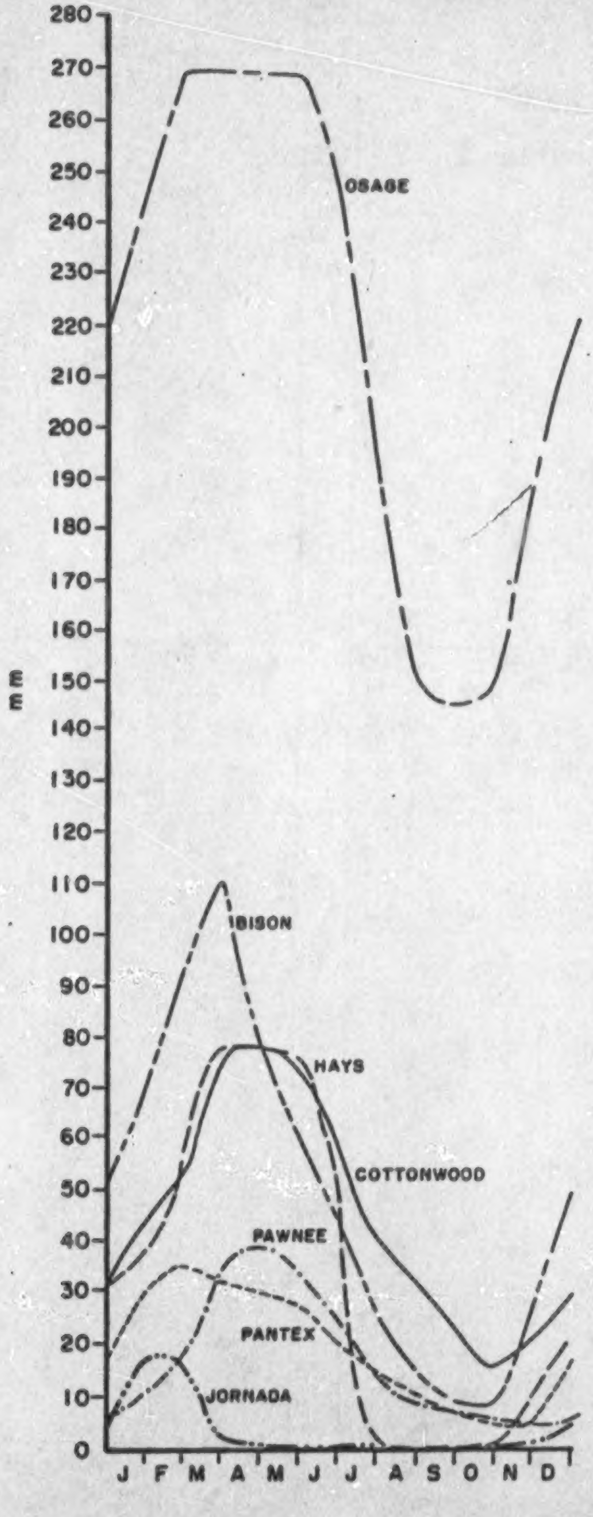


Figure 12. Soil water storage (W_2) at different Grassland Biome sites based on long-term average data (235).

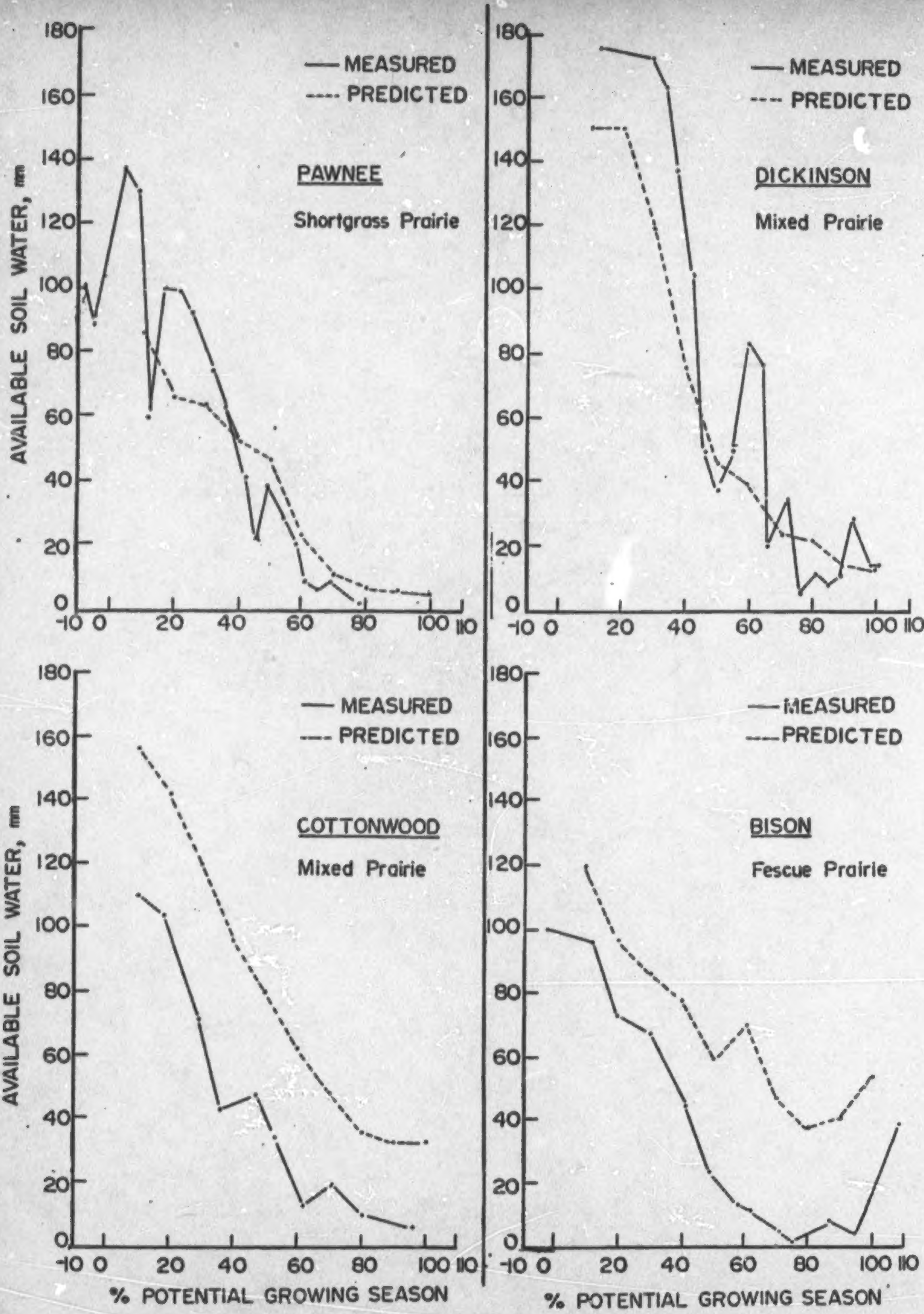


Figure 13. Available soil water (above 1870 field minimum) measured and preducted from estimates of soil water storage calculated by the method of Thornthwaite and Mather (236), Grassland Biome, 1970 (237).

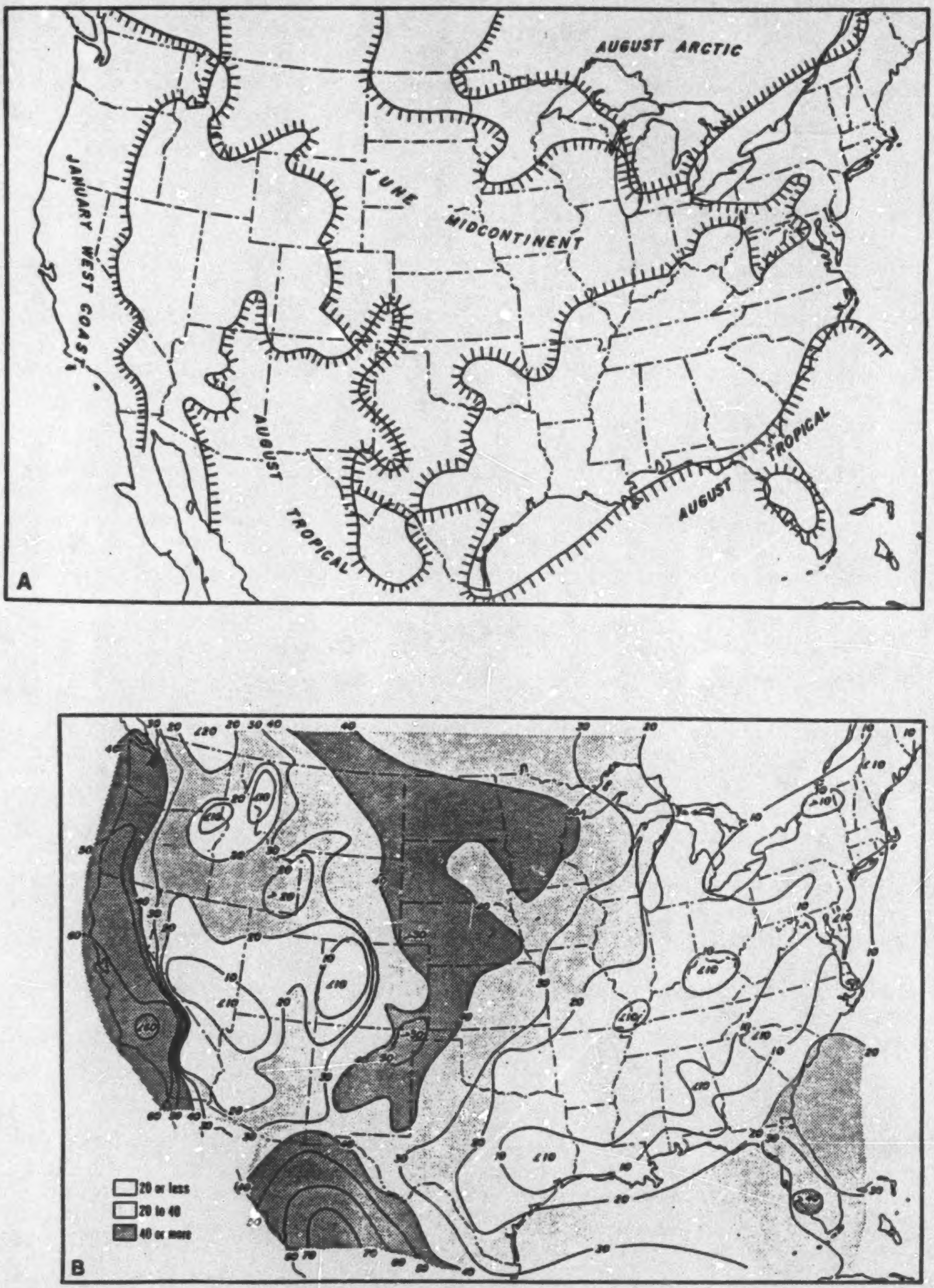

AUGUST ARCTIC
JUNE
MIDCONTINENT
JANUARY WEST COAST
AUGUST
TROPICAL
TROPICAL
AUGUST
A
20 or less
20 to 40
40 or more
B

Figure 14. Months of dominant concentration of precipitation. A. Degree of seasonal concentration of precipitation, 1951-1960. B. Figures express vector sum of monthly precipitations (months 30° apart around circle) as percent of scalar sum (231 from Markham, 239).

than the air above and to the sides (Fig. 15, 231). This region is associated with a very high incidence of severe thunderstorms, hail and tornadoes.

2.2.1.2 Variability

While all attributes of the Great Plains climate are variable, the most characteristic attribute is the striking variability of precipitation, especially the variability about the lower limit for crop production. Coefficients of variability range from 20 to 40% with 21 to 29% of the years within 25% of the 50-year average (231).

Pierre, South Dakota, lies on the one hundredth meridian near the border between the subhumid and semiarid climatic zones (Fig. 16, 304). Schumacher (302) analyzed an 81-year precipitation record from Pierre and found that according to Thornthwaite's 1931 climatic classification scheme (303) that 6% were arid, 41% semiarid, 38% dry subhumid, 15% moist subhumid, and 0% humid. The extreme fluctuation of the semiarid-subhumid boundary over a five-year period is shown in Fig. 17 (305).

Not only is precipitation extremely variable, but wet and dry years tend to come in bunches. Clawson (306) calculated the coefficient of variability sequence which measured the tendency toward bunching and found greater values in the northern Great Plains (Fig. 18, 306). This tendency is shown graphically for Pierre (Fig. 19, 307). Older data from Miles City, Montana, showed similar groups of years (Table 2, 335).

Severe droughts have plagued the Great Plains since before the early days of settlement. Yet, the alternation of periods of favorable and unfavorable precipitation have been deceptive, even though warnings were sounded (311, 312), especially after the 30s (308, 309, 310, 315, 316, 317). The effects of drought on the Great Plains have been described (328 and references, 318, 319,

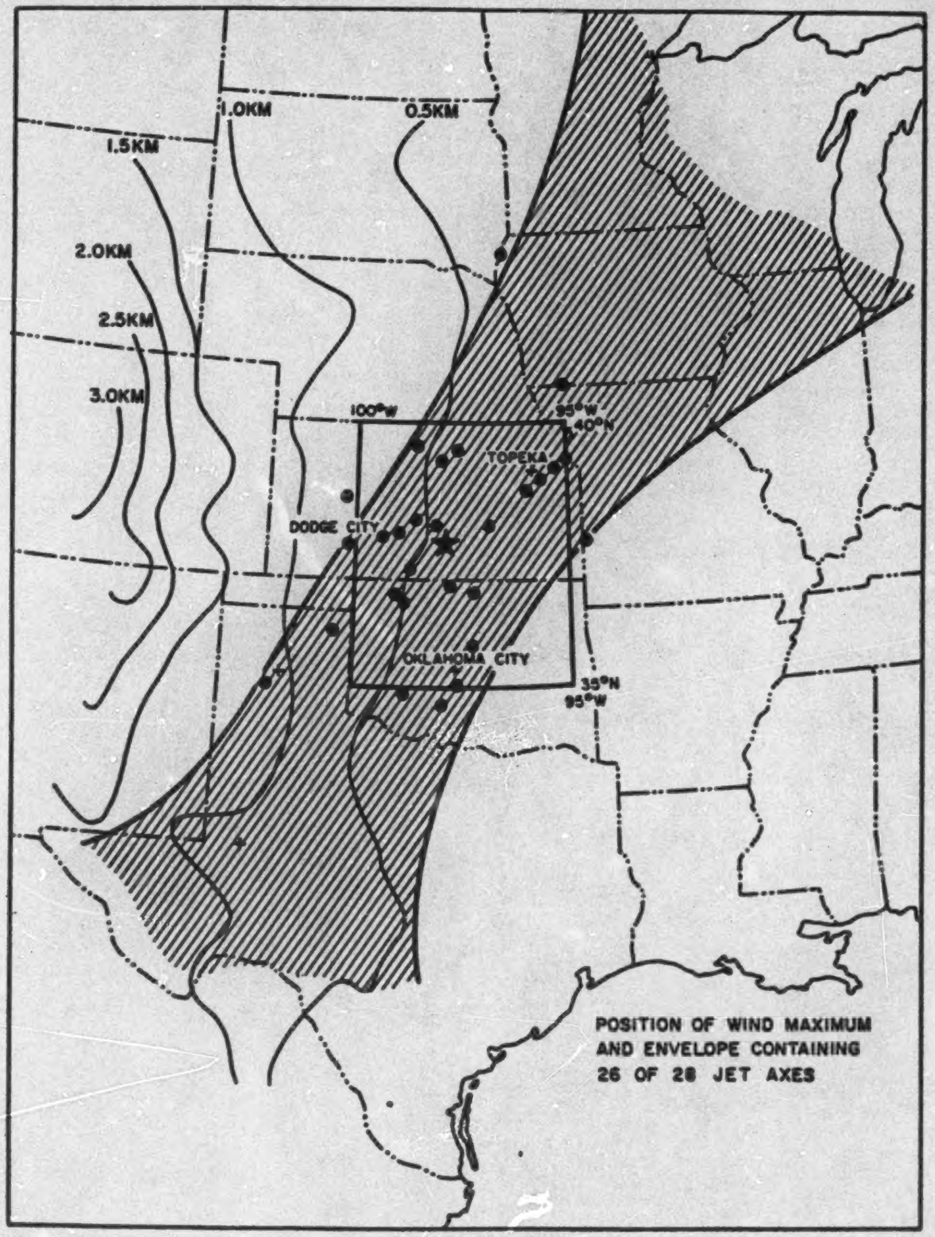

1.0KM
0.5KM
1.5KM
2.0KM
2.5KM
3.0KM
100°W
95°W
40°N
TOPEKA
DODGE CITY
OKLAHOMA CITY
35°N
95°W
POSITION OF WIND MAXIMUM
AND ENVELOPE CONTAINING
26 OF 28 JET AXES

Figure 15. Location of axis of low-level jet in 26 of 28 cases, 1959-1960. Star indicates median latitude and longitude of all 28 cases, centers of which are shown by dots. Land elevations above sea level shown by solid lines (231).

THE PROFESSIONAL GEOGRAPHER

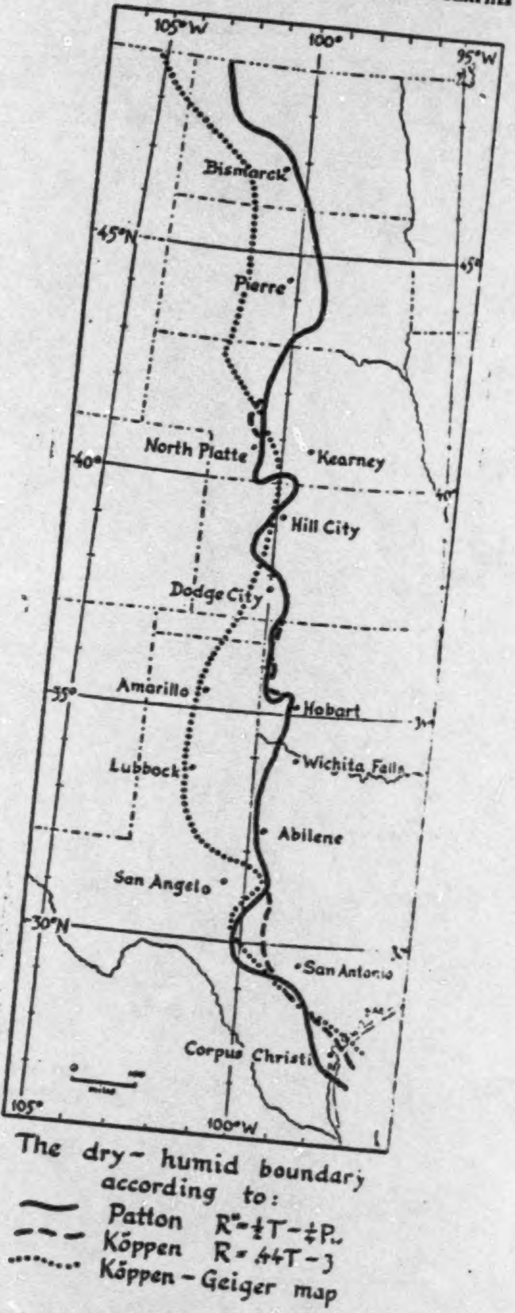

105°W
100°
95°W
45°N
45°
40°
40°
35°
35°
30°N
30°
105°
100°W
miles
Bismarck
Pierre
North Platte
Kearney
Hill City
Dodge City
Amarillo
Hobart
Lubbock
Wichita Falls
Abilene
San Angelo
San Antonio
Corpus Christi
The dry-humid boundary according to:
Patton R″=¼T−¼Pw
Köppen R=.44T−3
Köppen-Geiger map

Figure 16. The boundary between the dry and humid climates in the Great Plains (304).

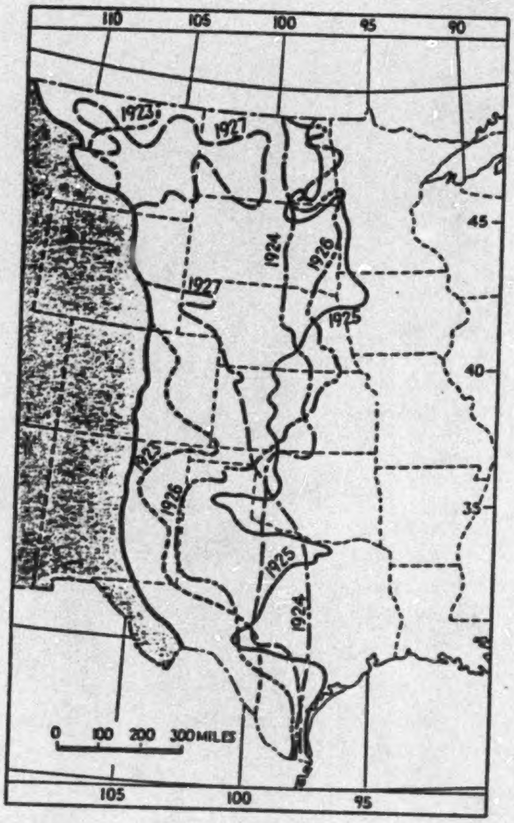

110
105
100
95
90
1923
1927
45
1924
1926
1927
1925
40
1925
1926
35
1925
1924
0 100 200 300 MILES
105
100
95

Figure 17. The fluctuating semi-arid subhumid boundary for the Great Plains over the years 1923-1927 (305 from 337).

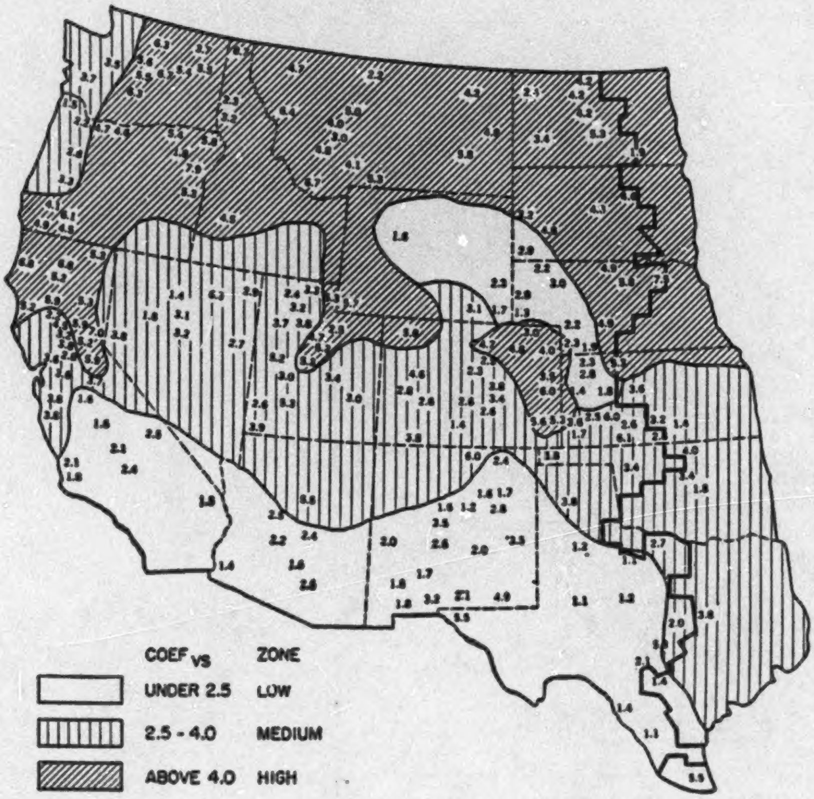

COEF VS
ZONE
UNDER 2.5
LOW
2.5 - 4.0
MEDIUM
ABOVE 4.0
HIGH

Figure 18. The distribution of COEFVS (coefficient of variability sequence, a measure of clumping) of annual precipitation (306).

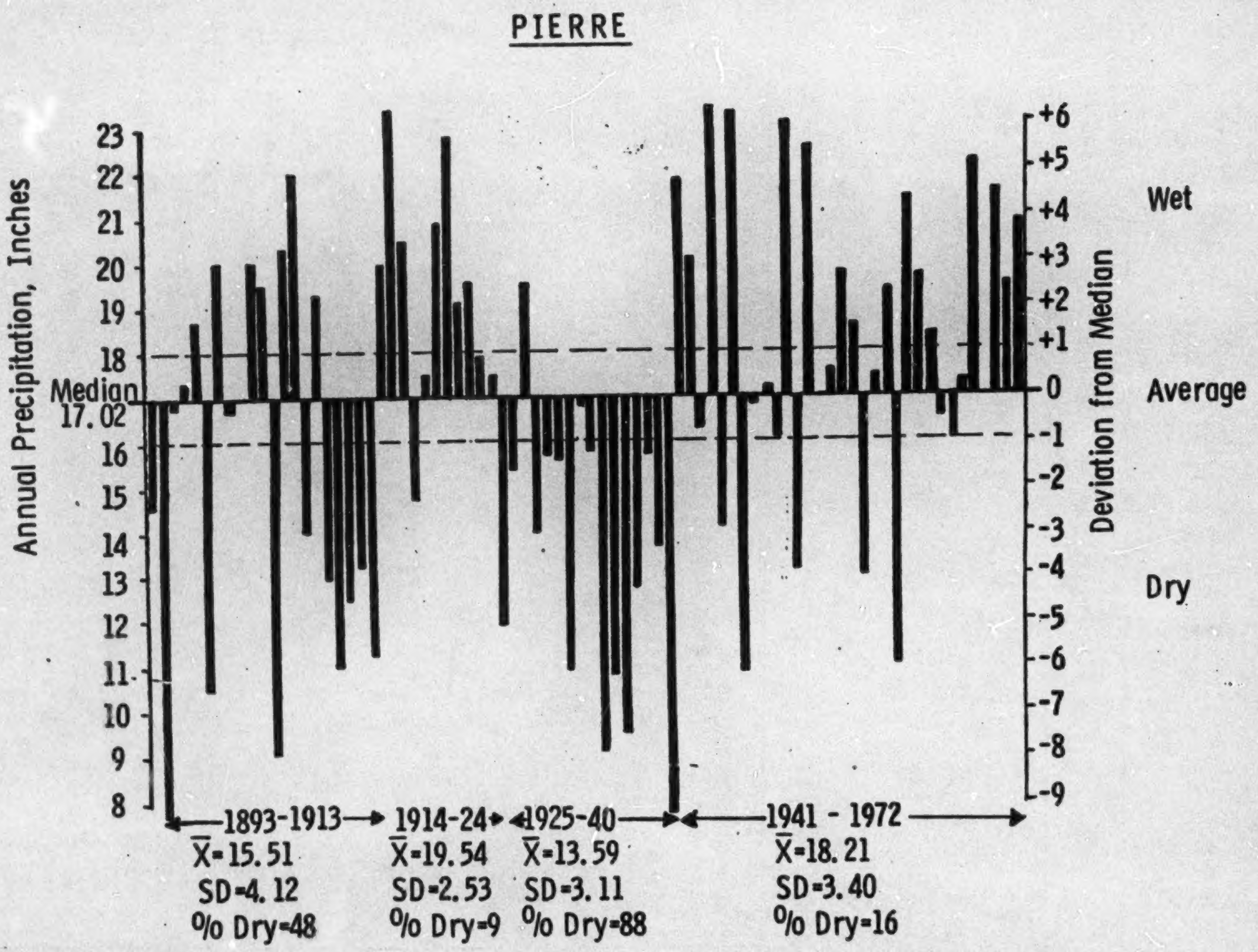


Figure 19. Total annual precipitation at Pierre, South Dakota, 1893-1972, showing deviations from the median. Mean, standard deviation and percent years more than one inch below the median are shown for different year sequences (307).

Table 2. Distribution of Precipitation (April through August) by Groups of Years, Miles City, Montana, 1878-1946 (335)

Years	Duration	Below average[1], %	Killer years[2], %	Cumulative departure, in.
1878-1880	3	0	0	
1881-1904	24	62	12	-15.8
1905-1916	12	17	0	+25.2
1917-1939	23	74	35	-25.5
1940-1946	7	0	0	+16.4

[1] Average was 8.2 inches.

[2] "Years when drought was so severe it killed the grass on the range."

321, 331, 332, 334) and reviewed (329), their severity assessed (313, 324, 325), management recommendations made (3, 330), books on drought written (197), bibliographies prepared (322), symposia held (323), social and political impacts evaluated (326), governmental strategies studied and pondered (327) and possible correlations and causes assessed (232, 211, 320, 333, 336 and references), yet drought remains a dominant feature of the Great Plains environment which must never be ignored.

2.2.2 Possible Future Climatic Regimes

The climate of the Great Plains which those of us alive today have experienced and view as normal is really quite abnormal from a longer perspective (338, 340). "Since 1880 only half of the decades in the Northern Hemisphere have been as warm or warmer than 1960-70. Our evidence indicates that since A.D. 1700 all 30 year periods have been colder than the 1931-60 period. About 90% of the past million years have been colder than our own time" (336 quoted from 339). A general cooling trend began about 1950 and may mark a return to more "normal," cooler and more variable weather (336).

Lawson used historical weather records, diaries of early travelers, army post records, and carefully calibrated tree ring records to reconstruct the climate of the Great Plains in the 1800s prior to 1850. He concluded that "it seems probable that the period 1800-1850, as part of the Little Ice Age, experienced a higher precipitation effectiveness (and probably a higher precipitation) than the periods 1851-1900 and 1901-50" (341). Bryson and Hare (231) drew a similar conclusion and suggested that the climate of this period may be a good model for the future.

Buried soils lying below wind-laid deposits in the Plains (342, 343) provide evidence of wide-spread drought and attendant wind erosion (344) which is confirmed from tree-ring records (345, 346, 347).

Thompson found that seven major droughts, occurring in Nebraska between 1800 and 1960, all occurred after the peak of the minor sunspot cycle and before the peak of the major cycle (Fig. 20, 333). He predicted that the next prolonged period of favorable weather should be in the 80s. While these data are striking, the mechanism is not understood and many factors are operative in determining the occurrence and the timing of drought.

Interacting with the complex of factors determining natural climatic fluctuation or change are the effects of human activity on world climate (348, 360) and on the climate of the Great Plains. Effects of human activities include increased particulate matter in the atmosphere, resulting from industrial pollution, windblown soil, slash burning, and increased carbon dioxide mainly from cumbustion of fossil fuels. Carbon dioxide is being produced faster than it can be assimilated by the oceans and by photosynthesis.

The net effect of the particulate matter is to reflect more solar radiation and decrease temperature, while the effect of increased carbon dioxide is to absorb more heat in the lower levels of the atmosphere. Some scientists expect particulate matter to have the greater effect (361, 362), others expect the carbon dioxide effect to be dominant (356, 357, 358, 359) with carbon dioxide levels expected to double by the year 2050 with a range of 2010 to 2100. The projected global warming trend is expected to be apparent within the next decade and clearly identifiable by the end of the century (349). As a result, the rangelands of the central Great Plains are expected to become warmer and drier (Table 3, 349), possibly resulting in reduced forage production, reduced proper stocking rates, shifts in botanical composition, increased incidence of crop failure and increased conversion from cropland to range (349). Drought frequency also may be increased (358). A large number of testable hypotheses have been generated, requiring research (349).

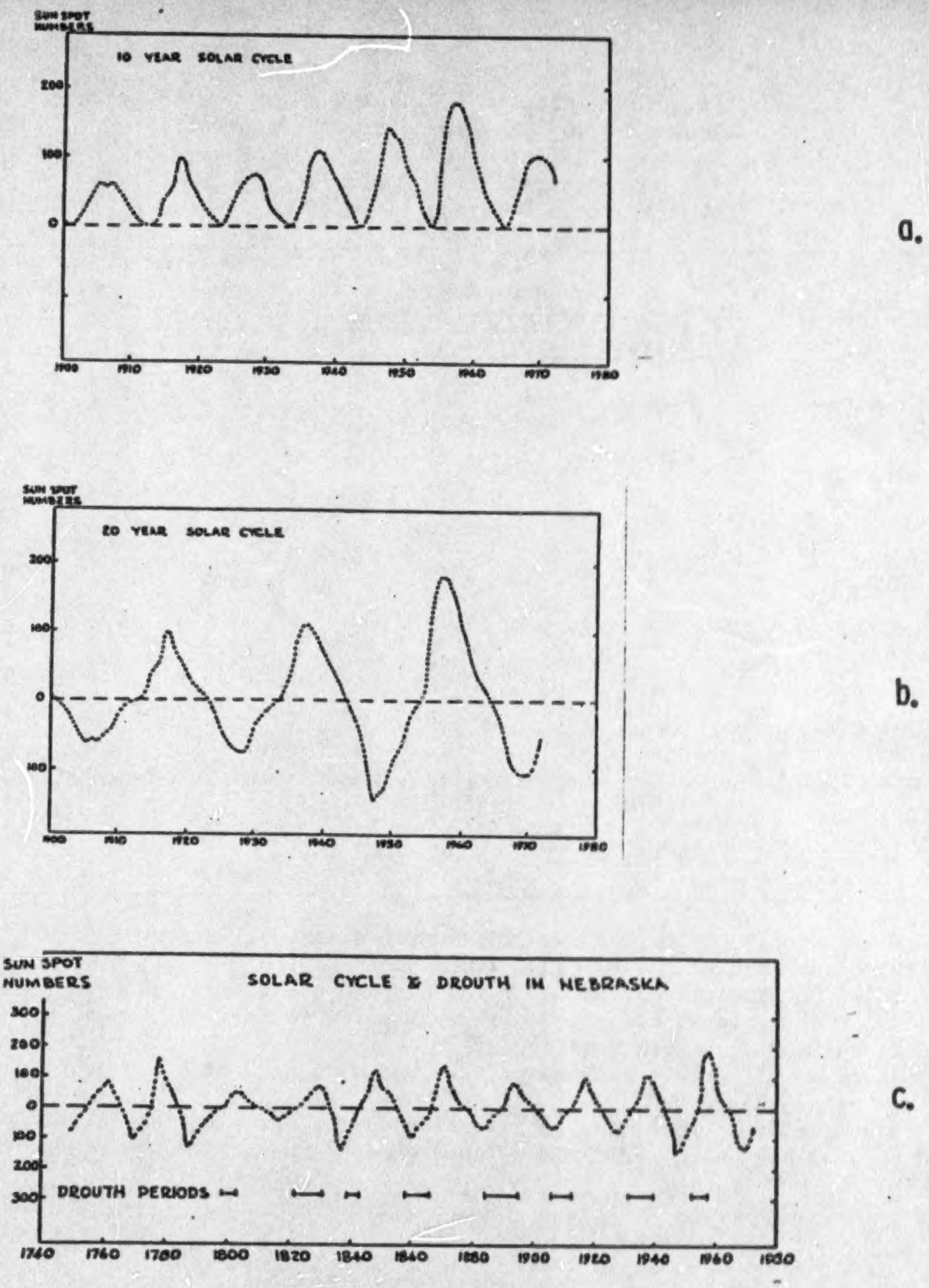


Figure 20. Sunspot cycles (a), double sunspot cycles (b), and coincidence of double sunspot cycles and major drought periods in Nebraska (c) (333).

Table 3. Predicted Effect of Global Warming Due to Increased Atmospheric CO_2 on Temperature, Precipitation and Water Relations of Rangelands of the Central Great Plains of Northeastern Colorado (data from 349)

Climatic element	Season	Derived from simulation model[1]		Derived from historical data for warmer than current conditions		
		(350)[2]	(351, 352)	(353)[3]	(354)[4]	(355)[5]
Temperature, °C	Annual	+6 to 8			+2	
	Winter		-<2.5	+1 to 2		
	Summer		+2.5 to 5.0	0		
Precipitation	Annual				-	-
	Winter			0 to -		
	Summer			-		
Precipitation Minus evaporation, cm day^{-1}	Annual	0, +.05				
Soil water, cm	Annual	1, -.5				

[1] These models assume that equilibrium or near equilibrium has been reached following an immediate doubling of atmospheric CO_2.

[2] Based on generalized continent and also on quadrupling of CO_2.

[3] Based on regional climatic anomalies during years with warmest Arctic winters and summers, 20th century data.

[4] Based on difference between coldest and warmest Arctic temperatures, 20th century data.

[5] Based on differences in precipitation during the Alti-thermal Period, 4000 to 8000 B.P. when world was a few degrees warmer.

While the details of the future climate and even the direction of change is unknown, we can be certain that through the next century the Great Plains will remain a land of extremes of heat and cold, of severe drought and abundant rain, of open winters and blizzards, of early springs and late frosts, of balmy days and cold, blue "northers," interspersed with tornadoes and hail.

2.3 Vegetation

The vegetation of the Great Plains region has been classified in various ways by different authors. In 1920 Clements systematized the vegetation of the region as True Prairie, Coastal Prairie, Mixed Prairie and Desert Plains (363). Launchbaugh compared maps produced by several authors (Fig. 21, 364). Kuchler's map (369) issued in 1964 at a scale of 1:3,168,000 is quite detailed. A more compact map (370) is included in the National Atlas of the United States. Each of the Great Plains states has a vegetation map, some of which are compatible with Kuchler, while others are more detailed. Copies usually can be obtained from the State Office of the Soil Conservation Service.

The U. S. Forest Service (371) used Kuchler's map of potential vegetation types (369, 370) and grouped his types into ecosystems. Four ecosystems were recognized in the Great Plains region. Seven of Kuchler's types were combined into Plain grasslands, seven into Prairie, five into Texas savanna and only one into Shinnery. The location of these ecosystems is shown in Fig. 22 (371). This is the classification used in the Forest-Range Environmental Study (225) and in the Resources Planning Act reports (226).

The vegetation of these ecosystems was described as follows (371):

Plains grasslands: "Short, warm-season grasses predominate in this ecosystem, and there is a minor interspersion of forbs and shrubs. Vast stretches are dominated almost exclusively by blue grama, buffalo grass being

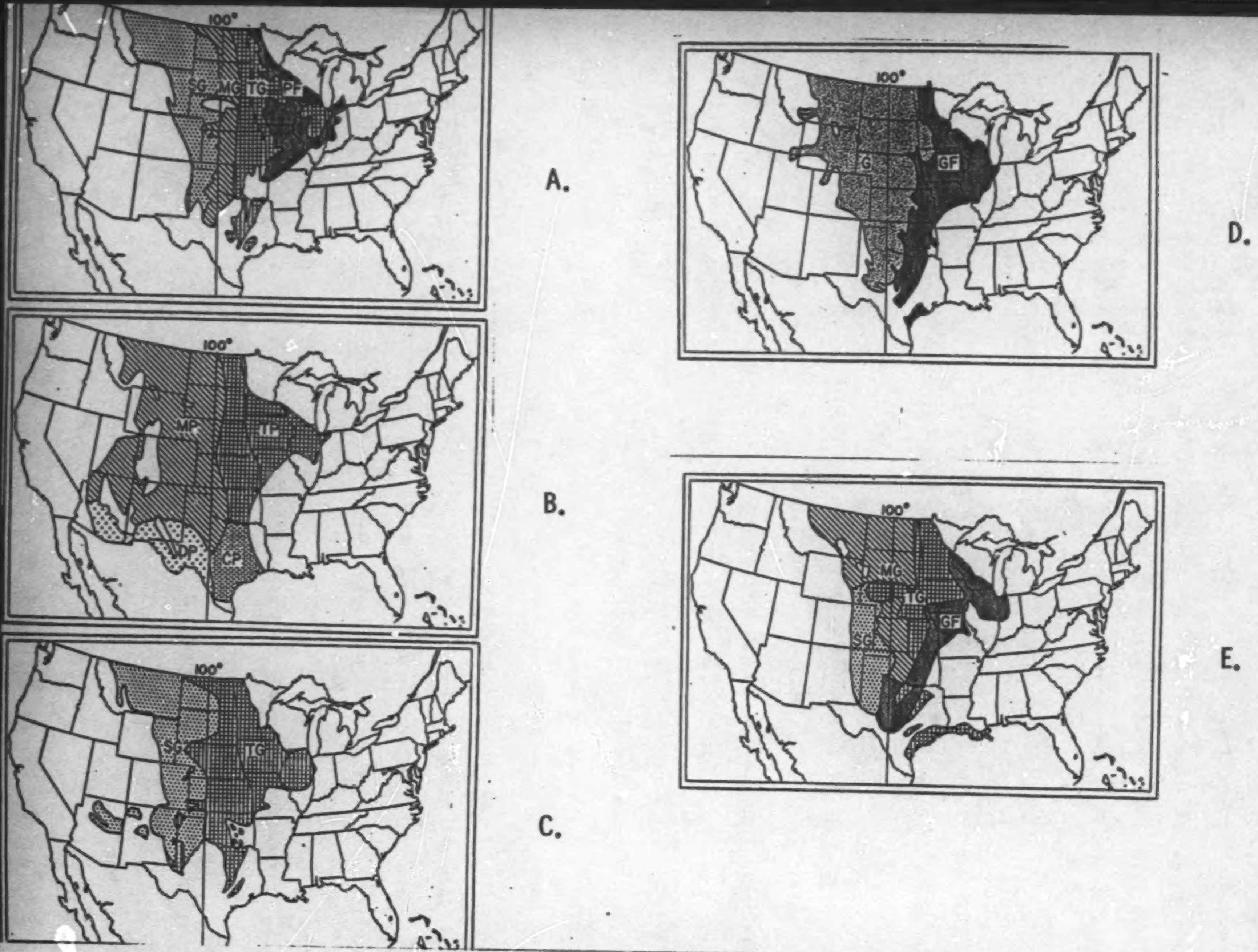

A.
100°
SG
MG
TG
PF
B.
100°
MP
TP
DP
CP
C.
100°
SG
TG
D.
100°
G
GF
E.
100°
MG
TG
SG
GF

Figure 21. Generalized classification of the vegetation of the central United States grasslands according to various authors (364). A. Carpenter (1940, 282), PF = Prairie-Forest Ecotone; TG = Tallgrass Prairie; MG = Mixed Grass Prairie; SG = Short-grass Plains. B. Clements and Shelford (1939, 283), TP = True Prairie; MP = Mixed Prairie; CP = Coastal Prairie; DP = Desert Plains. C. Shantz and Zon (1924, 284), TG = Tall Grass Prairie; SG = Short Grass Plains. D. Livingston and Shreve (1921), GF = Grassland-Forest Transition; G = Grassland. E. Launchbaugh (364) generalized from Kuchler (369).

Figure 22.—Forest and Range Ecosystems of the United States, 1977 (371)

a companion in many areas. However, the eastern part of the ecosystem is dominated by grasses of medium stature, such as western wheatgrass and needlegrass. The occasional shrubs include juniper, silver sagebrush, silver buffaloberry, and skunk-bush sumac in the northern reaches and rabbit-brush and mesquite in the southern part. Forbs are generally quite common, but many are ephemerals."

Prairie: "The prairie ecosystem is known to many as the tall-grass or true prairie. Bluestems constitute about 70 percent of the vegetation and reach heights of 5 to 6 feet in lowland areas. Large numbers of flowering forbs are present but are usually overshadowed by the grasses. Most of the plants are classified as warm-season plants. Woody vegetation is rare. Willow occurs in some places in exceptionally moist areas of the northern part of the ecosystem, and needle-leaved evergreens and broadleaved deciduous trees are scattered in the southern part. Deciduous trees are common along permanent streams in the eastern portion."

Texas savanna: "This is a high-shrub savanna ecosystem with a dense to very open synusia of broad-leaved, deciduous and evergreen, low trees and shrubs and needle-leaved, evergreen, low trees and shrubs. The grass varies from short to medium tall, and the herbaceous vegetation varies from dense to open. Mesquite is the most widespread woody plant. Others are _Acacia_ spp., oaks, juniper, and ceniza along the Rio Grande valley and bluffs. _Opuntia_ spp. are widespread. The herbaceous plants are mainly bluestems, three-awns, buffalo grass, gramas, and curly mesquite and tobosa on the Edwards Plateau."

Shinnery: "The vegetation of the shinnery ecosystem is a midgrass prairie with open to dense stands of broad-leaved deciduous shrubs and occasional needle-leaved low trees and shrubs. The major shrubs are Havard oak and mesquite. Little bluestem and side-oats grama are the most common grass species.

Sand bluestem is sometimes locally common. Sand sagebrush and yucca are the most common low shrubs."

Since the four ecosystems that comprise the Great Plains region occur over large areas with variable precipitation and soils, the variation was grouped into four productivity classes within each ecosystem. The major characteristics are displayed in Table 4.

The Forest Service classification into ecosystems and productivity groupings includes the Cross timbers (K-75/84), Oak savanna (K-72/81) and Mosaic of bluestem prairie (K-73/82) as forest. In the opinion of the authors, these areas should be included as Prairie. These savannas, when protected from fire and grazed heavily, will form thickets of small trees with no value for timber. In near climax condition such areas are very productive ranges (373, 374).

Common names of range plants follow Beetle (274) whose scientific names should be checked against Shetler and Skog (275). Distribution of individual species is given in the Atlas of the Flora of the Great Plains (276). The literature on the vegetation of the central grassland is immense. Portions of the older literature were listed by Renner et al. (277) and the newer (1935-1977) by Vallentine (278). A selected bibliography on the natural vegetation of the 11 midwestern states lists 742 publications (279). A Grassland Biome project abstract bibliography includes 1,542 references on Shortgrass and Mixed-grass Prairie ecosystems (280). An incomplete bibliography of the central grassland contains nearly 7,000 citations (281). Consideration of the range vegetation of the grassland should include the papers of Sims and Singh summarizing some of the vegetation studies conducted in 10 grasslands under the Grassland Biome project of the U. S. International Biological Program (216, 217, 218, 219).

Table 4. Characteristics of Productivity Classes Within Ecosystems in the Great Plains Region[1/]

Ecosystems	Productivity class	Average peak above-ground herbage standing crop, lb/a	Plant communities of Kuchler[2/]	Soils (see Table 1, also ref. 228)	Approximate precipitation, in.
Plains grasslands	1	2000	K-60/67 Wheatgrass-bluestem-needlegrass	Mollisols	18
	2	1500	K-59/66 Wheatgrass-needlegrass	Mollisols, including Argiborolls and gently sloping Haplustolls	15
	3	1000	K-62/69 Bluestem-grama prairie K-57/64 Grama-needlegrass-wheatgrass K-61/68 Wheatgrass-grama-buffalograss	Mollisols, Entisols, some Aridisols	12
	4	500	K-58/65 Gramma-buffalograss K-76/85 Mesquite-buffalograss	Mollisols, Alfisols, some Entisols	20
Prairie	1	5200	K-66/74 Bluestem prairie K-68/76 Blackland prairie	Mollisols	20-30
	2	3000	K-69/77 Bluestem-sacahuiste prairie	Vertisols	
	3	2500	K-74/83 Cedar glades	Ultisols	42
			K-67/75 Nebraska sandhills prairie	Entisols	18-25
	4	1500	K-63/70 Sandsage-bluestem prairie	Mollisols (Ustolls), Entisols (Psamments)	12-20
			K-79/88 Fayette prairie	Alfisols (Ustalfs)	35-40
Texas savanna	1	2600	K-55/62 Mesquite-liveoak savanna	Entisols (Ustipsamments)	29
	2	2100	K-54/61 Mesquite-acacia savanna	Variable: Mollisols, Alfisols and Vertisols, with variable subgroups	
	3	>1500	K-77/86 Juniper-oak savanna	Variable: Mollisols (Haplustolls, shallow to bedrock and Pellusterts), Alfisols	
	4	>1600	K-38/45 Ceniza shrub	Vertisols	

Table 4. Continued

Ecosystems	Productivity class	Average peak above ground herbage standing crop, lb/a	Plant communities of Kuchler[2]	Soils (see Table 1, also ref. 228)	Approximate precipitation, in.
Shinnery	1	2000	K-64/71 Shinnery	Mollisols	15-25
	2	1500	K-64/71 Shinnery	Alfisols	12-18
	3	1000	K-64/71 Shinnery	Aridisols	15
	4	500	K-64/71 Shinnery	Entisols (Ustipsamments)	12-25

[1] Compiled and interpreted from reference 371.

[2] The first letter-number designation is from Kuchler (1970, 370). The number designation following the slash is from Kuchler (1964, 369).

3. HISTORICAL PERSPECTIVE

3.1 Pre-Columbian (381)

Paleo-Indian people probably entered North America across the Bering Land Bridge as glaciation began to wane and soon were found throughout the hemisphere. The advance of glaciation resulted in waves of ecosystems gradually replacing one another in response to climatic variation. As the glaciers retreated and the climate became warmer and drier, the area dominated by the Plains grassland advanced northward and eastward. During this period of stress (about 12,000 to 8,000 B.C.) mammoths, camels, horses, and other large herbivores became extinct possibly under hunting pressure. The Plains Archaic culture that developed changed from generalized hunting to specialized bison hunting. The culture was characterized by the domesticated dog as a beast of burden, stone tools, bone artifacts and bison dependence. Bows and arrows replaced the atlatl after about 400 A.D. Agriculture probably developed in middle America, spread to the southwestern United States and thence to the central river valleys and the eastern forests. These people had a complex social structure, cultivated domesticated corn, beans, squash, sunflowers, sumpweed, etc. and gathered many wild fruits, nuts, seeds and vegetables. In the eastern Plains were semi-sedentary village groups which cultivated maize and other crops in the alluvial valleys with hoes made from bison scapulae. Native vegetal foods and fauna, including bison were important.

3.2 Period of Exploration (286, 290, 291, 292, 293, 294, 386)

3.2.1 Spanish and French Period (1530-1803)

These were the groups of Indians encountered by Cabeza de Vaca, Coronado, Onate and DeSota when they entered the Plains and Prairies (Fig. 23). The

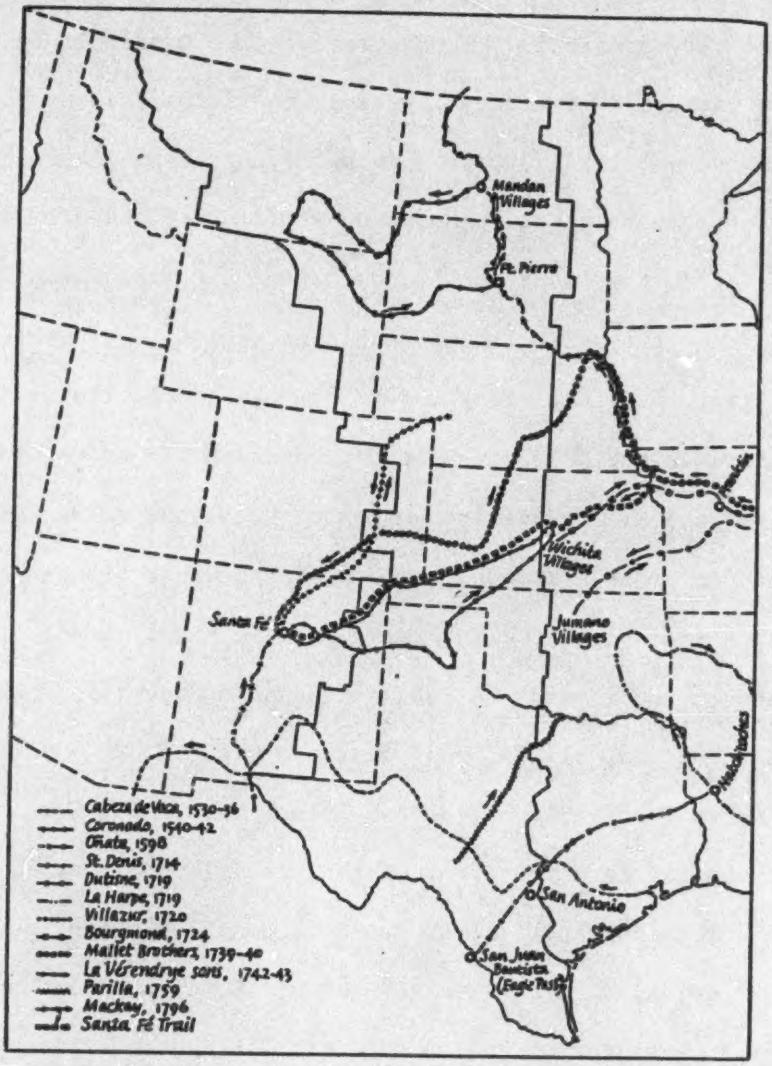

Mandan Villages
Ft. Pierre
Wichita Villages
Santa Fé
Jumano Villages
Natchitoches
San Antonio
San Juan Bautista (Eagle Pass)
Cabeza de Vaca, 1530-36
Coronado, 1540-42
Oñate, 1598
St. Denis, 1714
Dutisne, 1719
La Harpe, 1719
Villazur, 1720
Bourgmond, 1724
Mallet Brothers, 1739-40
La Vérendrye sons, 1742-43
Parilla, 1759
Mackay, 1796
Santa Fé Trail

Figure 23. Explorations in the Great Plains before 1800 (291).

cultures which they found were dynamic, finely-tuned to the variable and harsh environment and very adaptable. When horses became available by straying, trade or theft, they were quickly adopted, making the Plains Indians more mobile, better hunters and warriors, and thus intensifying their inherent characteristics. With English settlements along the east coast (≥1607), waves of tribes were displaced, resulting in the incursion of new tribes into the Plains. Between 1600 and 1750 all of the tribes in the Great Plains region incorporated horses into their way of life, thus initiating the golden age of the Plains Indian.

The Spaniards established missions and permanent settlements at Santa Fe (1609) and along the Rio Grande in New Mexico and later at San Antonio. However, they were never able to occupy the Plains because of the fierce resistance of the Comanches and Apaches. The French claimed the drainage of the Mississippi and Missouri (Louisiana) in 1682 and began to develop trade among the Indians of the prairies, plains, and mountains with incursions from the south and from the north (Fig. 23). After the French and Indian War, the Treaty of Paris (1703) gave the territory west of the Mississippi River to Spain and that east of the River to England. After the American Revolution the land west to the Mississippi belonged to the United States. However, Frenchmen continued to be influential in exploration and in the establishment of trading posts. Spain gave Louisiana back to the French in 1800, who sold it to the United States in 1803. When Lewis and Clark (1804-1806) made their journey to the Pacific and back, they were in territory already explored by the French, in some cases the Spanish, and in the north by English traders of the Hudson Bay.

3.2.2 American Period (1804-1846)

Between 1804 and 1846, several American expeditions were sent to explore the country (Fig. 24). However, fur traders by 1843 had already established 150

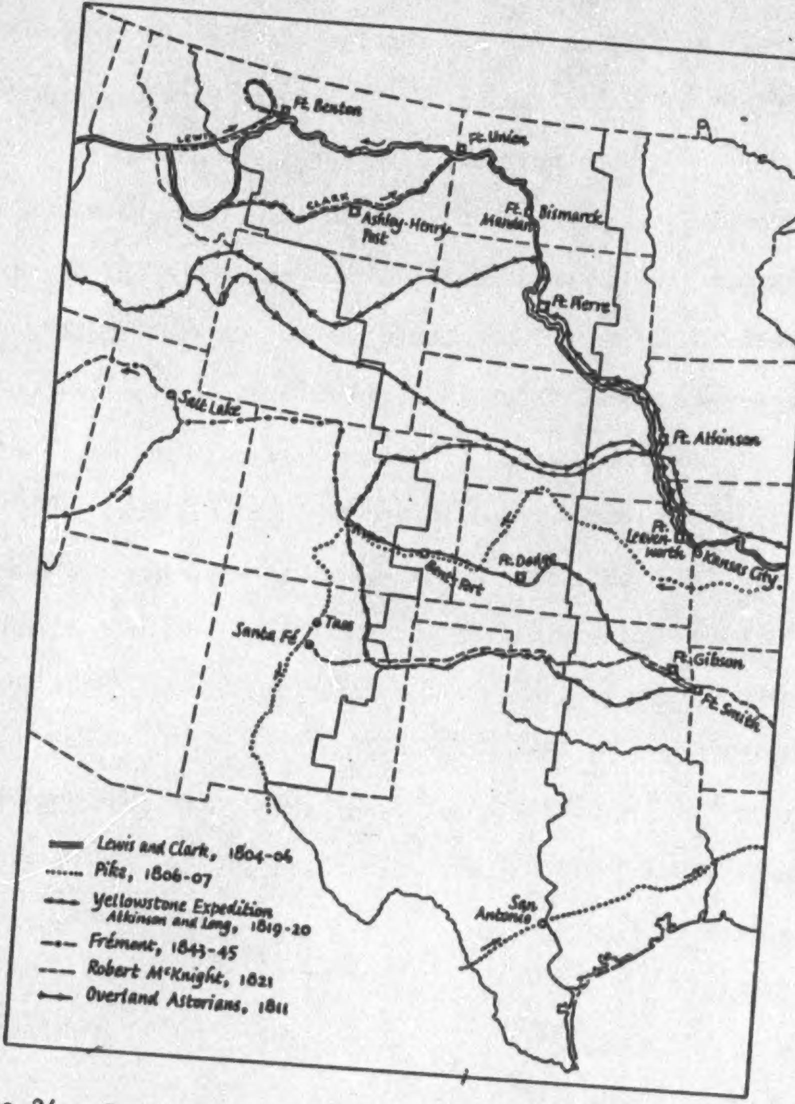

Ft. Benton
Lewis
Ft. Union
Clark
Ashley-Henry Post
Ft. Bismarck
Mandan
Ft. Pierre
Salt Lake
Ft. Atkinson
Ft. Leavenworth
Kansas City
Ft. Dodge
Bent's Fort
Taos
Santa Fé
Ft. Gibson
Ft. Smith
San Antonio
Lewis and Clark, 1804-06
Pike, 1806-07
Yellowstone Expedition Atkinson and Long, 1819-20
Frémont, 1843-45
Robert McKnight, 1821
Overland Astorians, 1811

Figure 24. Expeditions into the Great Plains, 1803-1846 (291).

trading posts. The explorers as well as various foreign visitors (Bradbury, Brackenridge: 1811; Maxmilian: 1833; Wislizenus: 1839) brought back reports of a treeless, barren region which became known as the Great American Desert.

In southern Texas, Spanish ranches began to flourish south of the Nueces River. However, Mexico gained its independence in 1821. Americans colonized the prairies of southeastern Texas in 1821 and Texas gained its independence from Mexico in 1836. The Texans took over the Mexican ranches and for the first time Anglo-Saxon people began to manage great herds of cattle in subhumid and semiarid regions on horseback. As soon as it became available in 1836, the six shooter became the preferred weapon from horseback, replacing the rifle and enabling the settler to be competitive with the Comanche. During the period of independence Texas developed land policies which provided for the disposal of operating-size ranch units to its citizens.

Texas was annexed in 1846 and its additional lands purchased by the United States (Fig. 25). The Mexican War (1846-48) was fought and the Mexican cessian added to United States territory.

3.3 Settlement East and West of the Plains (1846-c1875: 286, 291, 292, 293, 294, 295, 296)

The Oregon trail was opened in 1843. Gold was discovered in California in 1849, in Colorado in 1858 and in Montana in 1862. The Laramie Treaty of 1851 allowed travel across the Plains and settlers crowded into the prairies, began settlements and crossed the Plains (Fig. 26) in ever-increasing numbers. Spurred on by the Kansas-Nebraska Act of 1854 and especially by the Homestead Act of 1862 the prairies and the mountain valleys were settled, leaving the Great American Desert largely to the buffalo and the Plains Indians. Railroads with federal subsidy began to enter the Plains. The Indian tribes became

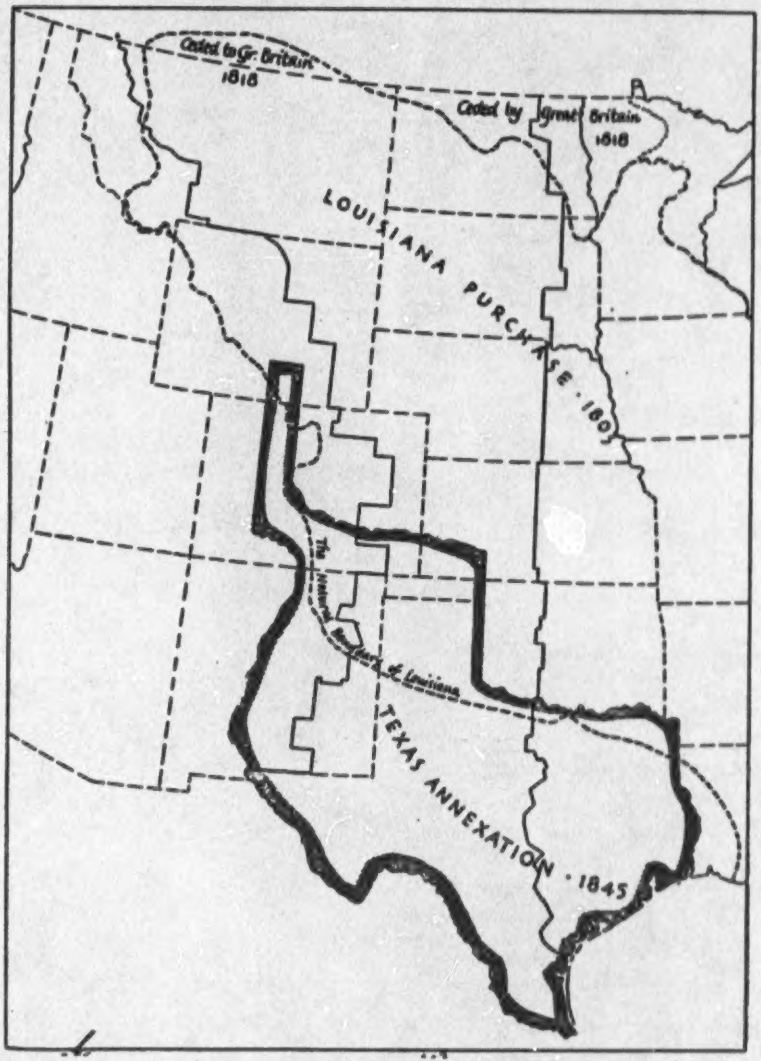

Ceded to Gr. Britain 1818
Ceded by Great Britain 1818
LOUISIANA PURCHASE · 180
The Natural Boundary of Louisiana
TEXAS ANNEXATION · 1845

Figure 25. The Louisiana Purchase, 1803, and the Texas Annexation, 1845 (291).

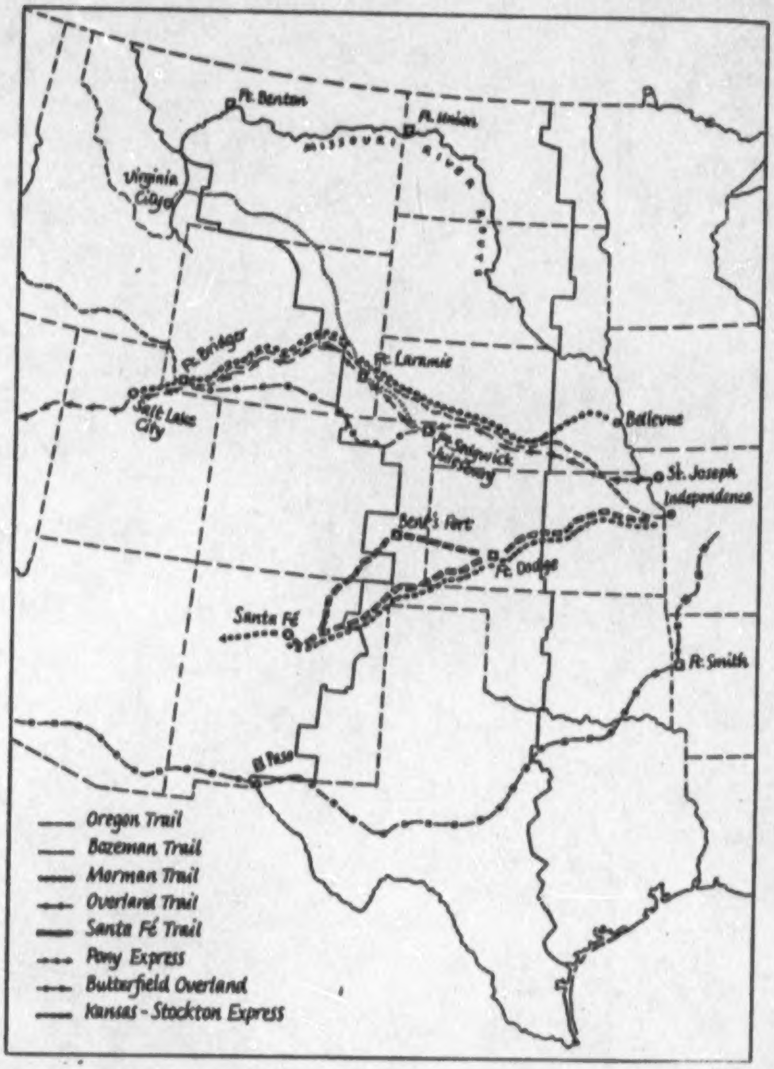

Ft. Benton
Ft. Union
Missouri River
Virginia City
Ft. Bridger
Ft. Laramie
Salt Lake City
Bellevue
Ft. Sedgwick
Julesburg
St. Joseph
Independence
Bent's Fort
Ft. Dodge
Santa Fé
Ft. Smith
El Paso
Oregon Trail
Bozeman Trail
Morman Trail
Overland Trail
Santa Fé Trail
Pony Express
Butterfield Overland
Kansas-Stockton Express

Figure 26. Nineteenth-century avenues of travel across the Great Plains (291).

alarmed and after the Civil War, in spite of the Laramie Treaty of 1868, driven on by the concept of Manifest Destiny and the push of western expansion, the extermination of the buffalo and the conquest of the Indian began. Simultaneously, trail drives of cattle from Texas to northern markets began. Some had been made earlier, but after the Civil War great herds were driven north (Fig. 27) beginning in 1866. Sheep also crossed the Plains (Fig. 28). The southern tribes were contained by 1874, the northern tribes by 1876, and, almost simultaneously, the buffalo were exterminated with the last hides being shipped in 1884. The land was open, awaiting settlement.

3.4 Settlement and Attempted Conquest of the Plains, 1876-1945: Seven Decades of Failure

3.4.1 The Record (286, 287, 288, 289, 291, 292, 297, 298, 299, 376, 377, 378, 379)

Eastern and European investors moved in first, bringing great herds onto free range where the grass was thought to be inexhaustible, thus overgrazing the range. The sheepmen quickly followed (Fig. 28). The settler, held back by the concept of the Great American Desert, reinforced by drouth during the 1870s, stayed back in the Prairies. However, with encouragement by the railroads; development of barbed wire, sod houses, deep-well drilling, and windmills; and by a series of good years in the late 70s and early 80s, the settlers poured into the Plains. Drought and blizzards terminated the free range operation and forced the provision of emergency feed. Settlement forced the ownership of land and the development of modern concepts of ranching began to emerge.

The droughts of the early 70s probably caused Congress to pass the Timber Culture Act, 1873, which provided title for land if settlers would plant and maintain trees in the expectation that this would make the climate more humid;

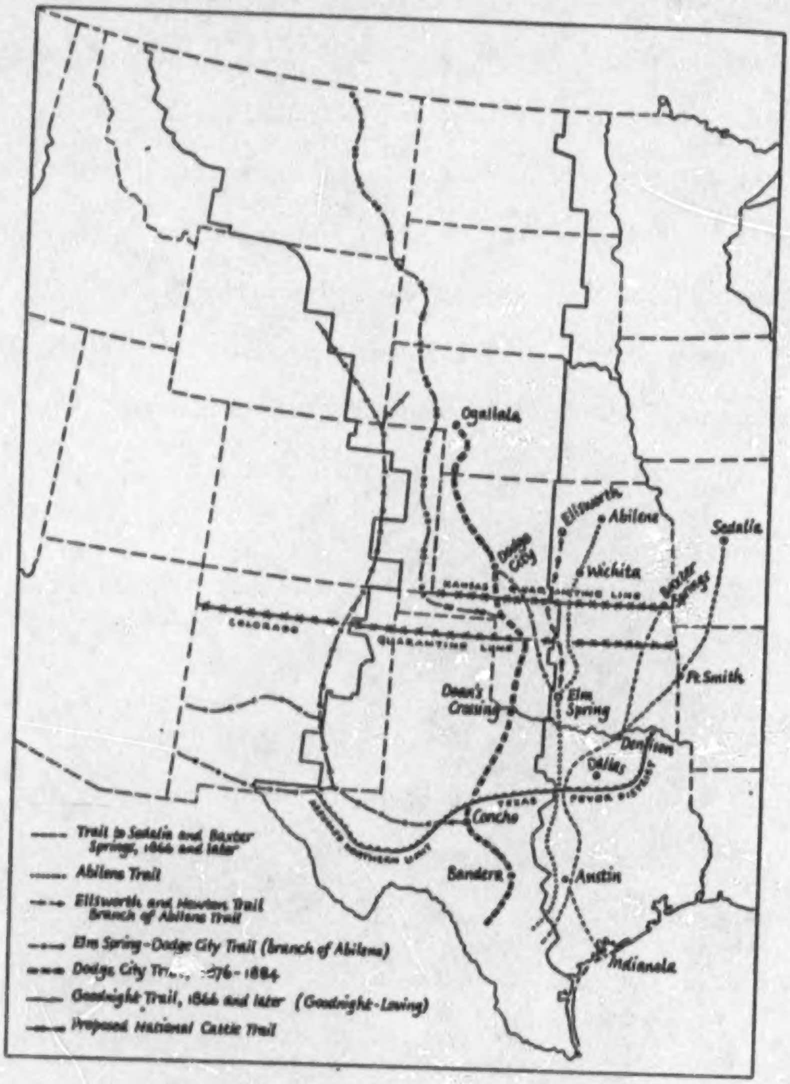

Ogallala
Ellsworth
Abilene
Sedalia
Dodge City
Wichita
Baxter Springs
KANSAS QUARANTINE LINE
COLORADO QUARANTINE LINE
Ft. Smith
Doan's Crossing
Elm Spring
Denison
Dallas
TEXAS FEVER DISTRICT
Concho
Bandera
Austin
Indianola
Trail to Sedalia and Baxter Springs, 1866 and later
Abilene Trail
Ellsworth and Newton Trail Branch of Abilene Trail
Elm Spring-Dodge City Trail (branch of Abilene)
Dodge City Trail, 1876-1884
Goodnight Trail, 1866 and later (Goodnight-Loving)
Proposed National Cattle Trail

Figure 27. Cattle trails (291).

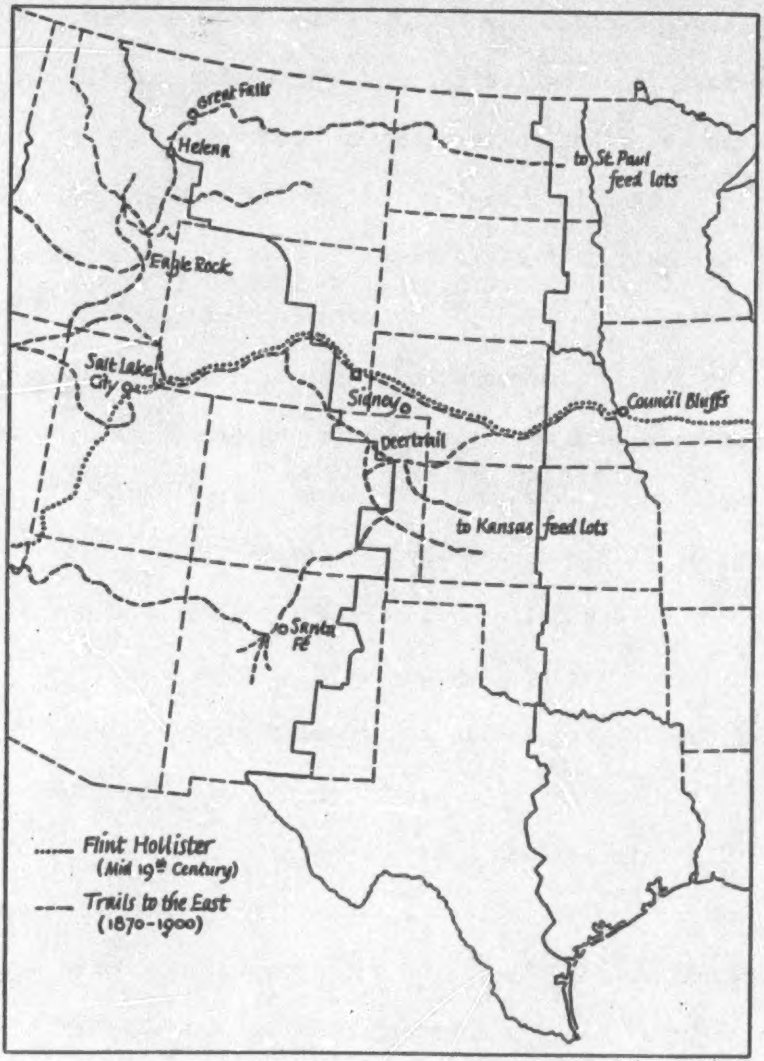

Great Falls
Helena
to St. Paul feed lots
Eagle Rock
Salt Lake City
Sidney
Council Bluffs
Deertrail
to Kansas feed lots
Santa Fe
...... Flint Hollister (Mid 19th Century)
---- Trails to the East (1870-1900)

__Figure 28__. Sheep trails (291).

also the Desert Land Act of 1877 which provided for sale of 640 acres with the requirement that part of it be irrigated. John Wesley Powell's report of 1878 recommended a reasonable land policy for the arid and semi-arid regions, which included disposing of land in large enough parcels to make a living on. In spite of his recommendations and the Texas land policy experience, Congress never developed a reasonable land policy for the West.

Drought during the 90s forced abandonment of some cropland. Overgrazing and range deterioration were widespread, bringing demand for the first experiments in range improvement which were conducted near Abilene and near Channing in Texas beginning in 1895 conducted by the newly-formed Division of Agrostology. The U. S. Department of Agriculture was formed in 1862, the Division of Botany in 1868, the Division of Agrostology in 1895, and the Forest Service in 1905, with an Office of Grazing Studies in 1910. Land-grant colleges were established by the Morrill Act of 1862 and were beginning to study the problem of range deterioration by the first decade of the twentieth century. Thus, the beginnings of range science can be traced to the mid 90s. The first experiment stations were established in the Plains during and after World War I. The first three textbooks in range management appeared during the 1920s.

Favorable years during the first decade of the 1900s, coupled with further development of the railroads brought a new wave of homesteading, momentarily slowed by drought during the early 1910s. However, favorable rainfall, the Enlarged Homestead Act of 1909 (320a), high wheat prices associated with World War I, and advertising of the merits of dry-land agriculture resulted in new rounds of cultivation. Slackened demand after the war brought crop surpluses. Favorable rainfall continued through the mid 20s and in some cases through the decade. The good weather and economic pressures resulted in heavy grazing.

Depression and severe drought during the 30s brought severe economic dislocation. The cultivated land blew, creating great dust storms, and the range was severely depleted, bringing national recognition to the critical problem. The federal government responded with a series of reports, laws and agencies: Soil Erosion Service, 1933; Taylor Grazing Act, 1934; Grazing Service, 1934; Soil Conservation and Domestic Allotment Act, 1936, setting up the Agricultural Conservation Program to be administered by the Agricultural Stabilization and Conservation Service; Senate Document 199, a report on the condition of the western range, 1936; Bankhead-Jones Farm Tenant Act, 1937, which authorized the purchase of bankrupt farms in the Great Plains and the reseeding of those lands to grass (those lands are now the National Grasslands).

During this period of national concern, additional experiment stations were begun in the Plains and range research was expanded with funding from the federal government and the states. With the return of favorable precipitation and favorable prices under the influence of World War II, range condition and the economic condition of farmers and ranchers began to improve. However, the disaster of the 30s made a long-lasting impression upon all who experienced it.

3.4.2 Reasons for Failure

One reason for failure of the first seven decades of American occupation of the Plains stands out above all others.

3.4.2.1 The Technologies, Attitudes and Institutions of the Humid East were Unsuited to the Subhumid and Semi-arid Plains.

The Plains were a new environment for Anglo-Saxon people and required radical change in technologies.

3.4.2.1.1 Changes made successfully.

Weapons: The singleshot rifle was of limited value in mounted combat and was replaced by the revolver.

Fences: Nails and stone were unavailable, therefore hedges were used and, later, barbed wire.

Home construction: Wood was not readily available, therefore sod, earth, or, locally, rock was used.

Fuel: Wood was not available, therefore, buffalo chips or cow chips, twisted grass, coal, etc. was used.

Water: Streams and springs were seldom available, therefore well-drilling and windmills, or impounded water was used.

Transportation: Streams were generally unavailable for transport, therefore freight wagons, railroads, later trucks were used.

3.2.2.1.2 Changes not made or made unsuccessfully. Overgrazing, especially of dry ranges, results in lowered range productivity. Furthermore, improvement is slow. This was not recognized.

Failure to keep a cover on the land results in wind and water erosion. This was not done.

Uncertainity of weather requires flexibility in ranch operations, farm operations and in financing. Operations were quite inflexible. Mortgage payments were fixed and inflexible.

The failure to realize the certainty of drought and of wet years resulted in stocking ranges at (or above) wet year capacities and failure to adjust downward in dry years. This same faulty perception caused widespread breakup of ranges in wet years for crop production with subsequent crop failure and abandonment.

The concept of plowing up range to make cropland was spoken of as putting land into production, whereas, reseeding or abandoning, was taking land out of production. This was done even though sustained production was greater in range in many cases.

Because of low precipitation and/or poor soils, more land is needed for an economic unit and population density is low. Despite adequate warnings, Congress ignored this basic principle in homestead legislation covering a period of more than 50 years. This resulted in farms and ranches that were too small or were a patchwork of ownership patterns. Failure to recognize this principle resulted in counties that were too small with higher costs of local government. It also resulted in too many colleges. For example, South Dakota, with less than 700,000 population, still has seven state-supported colleges and universities.

Practices recommended for ranchers by the experts or by the power structure often were those found to be successful in the humid east, but not adequately tested in the drier country.

3.4.2.1.3 Wrong ideas and attitudes. The major error underlying these mistakes was that proper management was management to conquer and control nature. A corollary of this misconception was that the bounty of nature was somehow inexhaustible. In the severe Plains environment, man must cooperate with nature for economical management of the range.

3.4.2.2 The Lingering Concept of the Great American Desert Fragmented the Region and Made Coordination Difficult.

The true Plains region does not occupy all of any state. The centers of power in each state of the region were located either in the Prairies on the east or the mountain valleys in the west. The railroads and major highways ran east and west across the Plains rather than through them. None of the land-grant colleges and very few other colleges were located on the Plains (Fig. 29). The colleges, especially on the eastern side, tended to be dominated by the philosophy of the humid lands.

3.4.2.3 A Conflict of Cultures Occurred Between the Plains and the More Humid Prairies, Between the Ranching and Farming Areas.

Webb (286) developed the concept of two cultures in collision on the Plains. One of these was the culture in which large herds of livestock were grazed in arid or semi-arid regions under the management of people with whom the horse was a way of life. The other was a culture from the humid forests where small herds of livestock were grazed in clearings or on crops under the management of people who used the horse as a beast of burden or an instrument of war, but not as a way of life. The first culture moved from the steppes of Asia through North Africa to Spain and thence to southern Texas and north through the Plains with the great herds of cattle and flocks of sheep. The other moved from Europe to the eastern United States and westward through the forest to the grasslands of the Plains. The second culture dominated the government, the financial agencies, and the educational institutions. The clash between these cultures was very noticeable during this period.

3.5 Conservation and Technology, 1946-1972

The memory of drought and depression was vivid during the early part of this period, but dimmed with the passage of time. Post war (World War II and

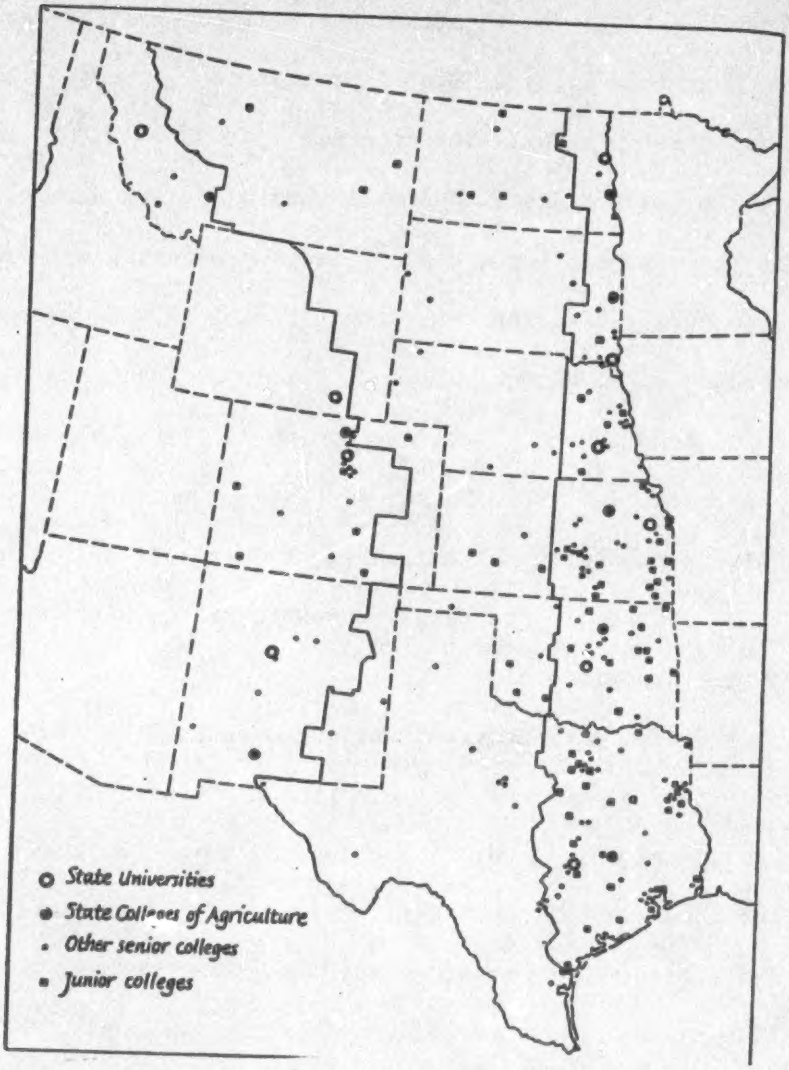

○ State Universities
● State Colleges of Agriculture
• Other senior colleges
▪ Junior colleges

Figure 29. Institutions of higher education in, and within a hundred miles of, the Great Plains (291).

Korean War) growth in technology coupled with favorable precipitation resulted in increases in agricultural production, surpluses, lowered prices, price supports and a Soil Bank program.

Increased research in all phases of agriculture brought continued increases in production. Low costs of fuel, machinery and fertilizer encouraged more intensive production practices. Feed surpluses encouraged high concentrate feeding of livestock.

Range research progressed more slowly. The Society for Range Management was formed in 1948. There was a steady increase in the number of colleges and universities with range management curricula and more universities granting Ph.D. degrees. More research was initiated with more intensive measures and better experimental design.

Severe drought was experienced during the 1950s on the southern Plains, but was less serious in the northern Plains. After the drought in the southern Plains and throughout the period in the north, there was a steady increase in the intensity of management of rangelands in terms of water development, fencing, development of introduced pastures, brush control, etc. The Great Plains Program passed in 1956 improved the application of good range practices throughout the Plains. Net returns to land on ranches remained relatively low, but escalation in land values tended to offset the low rate of return. A trend toward the use of more and more agronomic practices on rangeland continued throughout the period with bigger tractors, more efficient implements, more chemicals, more seeding and fertilization, supported by low fuel costs and low interest rates.

The Vietnam War and Great Society programs began to increase inflation, but rate of inflation and interest rates remained relatively low until near the end of the period. Precipitation was above normal in the northern Plains the entire period from 1946 through 1972 with the exception of about 5 years, depending on location. The ecology movement of the 60s resulted in a number of new laws that began to influence rangelands late in the period. In general, the period was prosperous with steady improvement in the level of technology and the application of technology and movement toward more intensive practices.

3.6 Inflation, Drought and Uncertainty, 1973-1980

Early in the period our grain surpluses were gone and the growth of world population indicated sustained demand. Low livestock prices, high grain prices, low fuel costs, low interest rates and rising land costs caused the breakout of large acreages of rangeland in the northern Great Plains for wheat production. However, in general, this period marked a drastic change from the trend toward the increased application of agronomic practices on rangeland. Decreasing petroleum supplies, the Arab Oil Embargo, and crises in the Middle East resulted in soaring costs of fuel, fertilizer, chemicals and machinery. Unsound fiscal and monetary policies; the Viet Nam war; the effect of environmental legislation on business; the vast increase in size and cost of government at the federal, state and local levels; as well as the oil crisis were blamed for roaring inflation. Drought continued, intermittently, throughout the period.

The economic feasibility of the use of introduced pastures to supplement ranges, a longterm keystone recommendation, was doubtful. Fertilization of ranges and pastures in the Plains was uneconomical, with few exceptions. High interest rates made investment in range improvement practices infeasible, if productivity increases required several years to come on line. Land prices no longer rose as rapidly as inflation, and in some cases, leveled or declined.

Borrowing on equity in Plains ranches continued for survival, but not for growth, improvement and development.

Technological development in all areas has been phenomenal. Ranchers, advisory technicians, bankers, research workers and educators are better informed about range science and more professional than they have ever been. Computer technology and improved decision-making tools provide opportunities for the most efficient management we have ever had. Advances in livestock breeding and cross-breeding, nutrition and management, advances in range science, especially in understanding energy flow in range ecosystems and development of new grazing systems offer great potential for future productivity. However, uncertainty in national defense and uncertainty in international, national, local and private finance result in an uncertain future for the rangelands of the Great Plains region.

4. RESOURCES AND USES

4.1 The Ecosystem Concept

The ecosystem concept is basic to understanding the nature of rangelands and their management for various uses (384, 2). An ecosystem is an ecological system in which all of the living and the non-living factors of the environment are integrated. A diagram of a range ecosystem is shown in Fig. 30 (307). The boxes are standing crops expressed as quantities present at some point in time. The solid arrows represent flows of materials expressed as rate processes or quantities per unit of time. The dotted lines represent the transfer of information or forces. The "bow-ties" represent controls that determine rates of flow. Operating conditions are shown inside double lines. Elements of the structure and function of range ecosystems in the Great Plains are displayed in Table 5.

4.2 Location, Extent and Ownership of the Rangelands of the Great Plains

The lands of the Great Plains region which are currently in range total near 250 million acres (Table 6) of which 70, 16, 2 and 11% are in the Plains grasslands, Prairie, Shinnery and Texas savanna, respectively. The distribution of ecosystems by ownership is shown in Table 7, using somewhat different data. The lands of the region are overwhelmingly in private ownership, although an appreciable acreage is managed by the Forest Service, primarily in the National Grasslands and a slightly larger acreage is administered by the Bureau of Land Management.

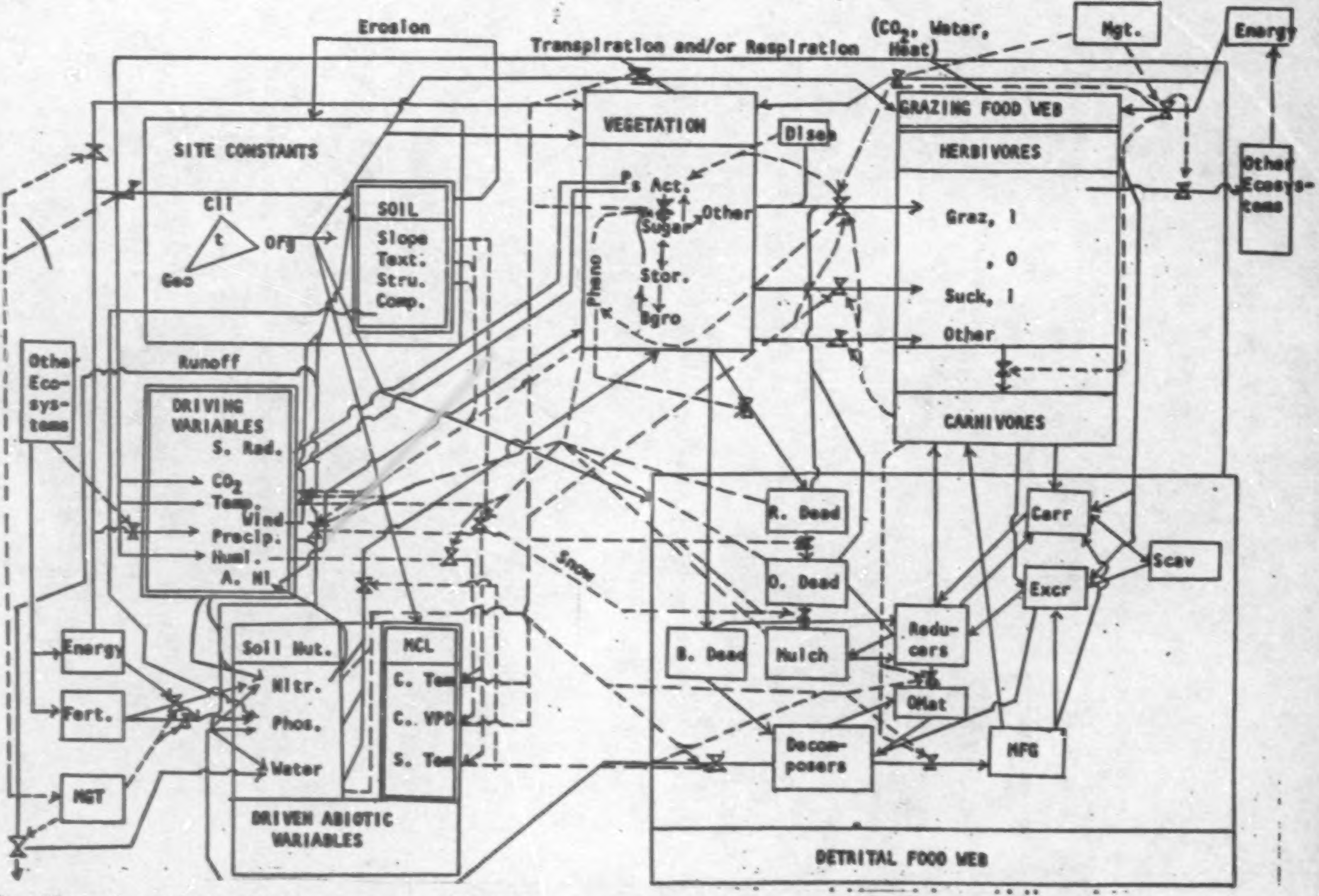

Erosion
Transpiration and/or Respiration
(CO$_2$, Water, Heat)
Mgt.
Energy
SITE CONSTANTS
Cli
t
Geo
Org
SOIL
Slope
Text.
Stru.
Comp.
VEGETATION
Dise
P$_s$ Act.
Sugar
Other
Stor.
Bgro
Pheno
GRAZING FOOD WEB
HERBIVORES
Graz, 1
, 0
Suck, 1
Other
CARNIVORES
Other Ecosys-tems
Other Eco-sys-tems
Runoff
DRIVING VARIABLES
S. Rad.
CO$_2$
Temp.
Wind
Precip.
Humi.
A. Ni
Snow
Energy
Fert.
MGT
Soil Nut.
Nitr.
Phos.
Water
MCL
C. Tem
C. VPD
S. Tem
DRIVEN ABIOTIC VARIABLES
R. Dead
O. Dead
B. Dead
Mulch
Decom-posers
Redu-cers
OMat
MFG
Carr
Excr
Scav
DETRITAL FOOD WEB

Figure 30. Flow chart for a land ecosystem showing site constants, driving variables, driven abiotic variables, vegetation, grazing food web, and inputs from other ecosystems. Compartments with single boundary lines show standing crops, solid arrows show flow rates; dotted arrows indicate effects on valves which control flow rates. Operating conditions are shown inside double lines (307).

Table 5. Structure and Function of Range Ecosystems in the Great Plains

---

I. Structure: Landscape matrix and quantities of weather elements; plant, animal and microbial communities with their dynamic spatial and temporal variations.

   A. Site Constants: Slowly changing site characteristics of geology, soils, topography, climate, providing land, mineral and ground water resources.

   B. Driving Variables: Rapidly changing elements of weather, such as solar radiation, precipitation, and wind.

   C. Vegetation: Dynamic, genetically diverse, self-renewing communities that provide for self-maintenance, soil formation, soil protection, food and habitat for the communities of the grazing and detrital food webs, differentiation of the microclimate, integrity of cycles of matter and plant resources for man.

   D. Grazing Food Web: Diverse interrelated communities, predominantly of biophages, including the following:

      1. Livestock: Cattle; sheep; goats; horses; burros; and elk, bison, and exotic wild animals.

      2. Game:

         a. Big Game: Mule deer; white-tail deer; antelope; big horn sheep; etc.; and elk, bison and exotic wildlife managed for hunting;

         b. Small Game: Cottontail rabbit, peccary, ground squirrel, etc.;

         c. Furbearers: Badger, beaver, bobcat, coyote, fox, jackrabbit, nutria, mink, muskrat, opossum, raccoon, weasel, etc.;

         d. Upland Game Birds: Ringneck pheasant, sharptail grouse, prairie chicken, sage grouse, wild turkey, dove, quail, partridge, etc.;

         e. Migratory Waterfowl: Ducks, geese, coot, sandhill crane, etc.

      3. Non-game Vertebrates (including both game and non-game): Reptiles, 64 species; amphibians, 23 species; birds, 350 species; fish, 134 species; mammals, 92 species.

      4. Invertebrates.

Table 5. Continued

E. Detrital Food Web: Diverse, interrelated communities, predominantly of saprophages, including scavengers; fecal feeders; reducers, mainly various arthropods and annelids; decomposers, mainly fungi, actinomycetes, and bacteria; microfloral grazers; and micropredators.

F. Driven Abiotic Variables: Rapidly changing properties of soil, microclimate and soil climate.

II. Function: Processes, such as insolation, radiation, conduction, precipitation, evaporation, erosion, deposition, photosynthesis, respiration, transpiration, translocation, herbivory, predation, parasitism, growth, reproduction, senescence, mortality, reduction, comminution, decomposition, resulting in energy flow and the cycling of matter.

A. Energy Flow and the Carbon Cycle: Provides the resources of the vegetation, the grazing food web and the detrital food web.

B. Cycles of Matter:

1. Hydrologic cycle, providing water resources (such as wetlands, springs, streams, and rechargeable ground water) for fish habitat and for the vegetation, the grazing food web, etc.

2. Nitrogen cycle, primarily supporting energy flow, the carbon cycle, etc.

3. Other cycles of matter.

C. Self-regulation.

Table 6. Rangeland Area by States and by Ecosystems[1/]

State	Plains grassland		Prairie		Shinnery		Texas savanna		Total	
	1000 a	%	1000 a	%	1000 a	%	1000 a	%	1000 a	%
Northern Plains										
Montana	36,994.4	21.1							36,994.4	14.8
North Dakota	12,089.8	6.9	206.1	0.5					12,295.4	4.9
Wyoming	20,667.3	11.8							20,667.3	8.3
South Dakota	21,922.4	12.5	1,410.8	3.4					23,333.2	9.3
Central Plains										
Colorado	15,270.0	8.7	1,723.4	4.2					16,993.4	6.8
Nebraska	9,746.9	5.6	14,525.1	35.3					24,272.0	9.7
Kansas	8,196.1	4.7	8,082.1	19.6					16,278.2	6.5
Southern Plains										
New Mexico	14,097.7	8.0			1,629.7	34.5			15,727.4	6.3
Oklahoma	4,877.9	2.8	3,818.2	9.3	604.8	12.8			9,300.9	2.5
Texas	31,376.1	17.9	9,292.2	22.6	2,491.3	52.7	28,428.8	100.0	71,588.4	28.6
Eastern Prairies										
Minnesota			155.8	0.4					155.8	0.1
Wisconsin			6.3	t					6.3	t
Iowa			38.4	0.1					38.4	t
Missouri			1,447.6	3.5					1,447.6	0.6
Louisiana			20.0	t					20.0	t
Tennessee			400.0	1.0					400.0	0.2
Alabama			52.8	0.1					52.8	t
Total	175,238.6		41,186.3		4,725.8		28,428.8		249,579.5	

[1/] USDA Forest Service (1980, 226).

Table 7. Rangelands of the Great Plains Region by Ecosystem and Ownership, 1970[1]

Ecosystem	Area, million acres	National forest system, %	Natural resource lands, %[2]	Other: Federal, %[3]	Other: Non-Federal, %
Plains grasslands	173.3	2.1	2.9	1.0	94.0
Prairie	38.4	0.8	0.0	0.5	98.7
Texas savanna	15.2	t[4]	0.0	0.7	99.3
Shinnery	2.0	5.0	t	t	95.0
Total	228.9	1.8	2.2	0.9	95.2

[1] Data from U.S. Forest Service (1975, 382). The data in this table are 1970 data from an earlier source than used in Table 6. The Eastern Prairies of Table 6 were not included and some changes were made in other classifications.

[2] Lands administered by Bureau of Land Management, Department of Interior.

[3] Lands administered by various agencies of the Department of Interior (excluding Bureau of Land Management) and the Department of Defense.

[4] t = trace indicates less than 50,000 a.

4.3 The Condition of Great Plains Rangelands

4.3.1 Range Condition

The state of health of the range expressed in terms of its potential is range condition. Range condition is quantitatively expressed as the departure from relicts of climax (385, 33, 386, 387, 388). While definition and procedures for calculating range condition differ somewhat between the Forest Service and the Soil Conservation Service, the data have been reconciled (226). Although range condition is primarily calculated from the vegetation, it is an index of the state of health of the entire ecosystem.

The distribution of range condition classes is somewhat similar in the four ecosystems (Table 8), with values slightly lower in Prairie and Shinnery. Range condition is higher in the northern than in the southern Plains states (Table 9). All states improved in range condition from 1963 to 1977 (Table 10) with greater improvement in the northern than in the southern Plains states. While the range condition classes are named differently, the four classes in the different tables should be approximately equivalent (226).

4.3.2 Herbage and Browse Production

Highest average annual peak standing crop of herbage and browse occurs in the Prairie followed by Texas savanna, Shinnery and then the Plains grassland (Table 11). Comparison of these values with net primary production data from the Grassland Biome project for the Plains grasslands (Mixed Prairie, Fig. 31, 219; Tallgrass Prairie, Fig. 32, 219 and Shortgrass Prairie, Fig. 33, 219) show that above-ground net primary production is much greater than peak standing crop and that grasslands in high range condition put a larger proportion of the net primary production above-ground than grasslands in low range condition.

Table 8. Range Condition Class by Ecosystem[1]

Ecosystem	Total 1000 a	Range condition class, % of total			
		Good	Fair	Poor	Very Poor
Plains grasslands	175,239	14.7	34.2	39.6	11.5
Prairie	41,186	13.9	34.2	38.1	13.7
Shinnery	4,726	16.5	27.7	40.5	15.3
Texas savanna	28,429	16.4	23.5	45.9	14.2
Total	249,580	14.8	32.8	40.0	12.3

[1] USDA Forest Service (1980, 226).

Table 9. Range Condition Class by States in the Great Plains Region[1]

State	Total range, 1000 a	Range condition class, % of total			
		Good	Fair	Poor	Very Poor
North Dakota	12,296	32.9	34.6	23.1	9.4
South Dakota	23,402	14.5	47.2	30.9	7.3
Nebraska	24,274	15.1	31.3	34.6	19.0
Kansas	16,278	10.3	45.0	33.8	11.0
Oklahoma	9,301	11.3	36.9	40.5	11.3
Texas	91,599	13.2	23.2	45.2	18.4

[1] USDA Forest Service (1980, 226).

Table 10. Change in Range Condition of Nonfederal Rangeland in the Great Plains States From 1963 to 1977[1]

State	Year	Range condition, % of area			
		Excellent	Good	Fair	Poor
North Dakota	1963	12	22	35	31
	1977	27	37	26	10
	Change	+15	+15	-9	-21
South Dakota	1963	9	21	38	32
	1977	13	47	32	8
	Change	+4	+26	-6	-24
Nebraska	1963	9	21	40	30
	1977	15	31	35	19
	Change	+6	+10	-5	-11
Kansas	1963	7	20	33	40
	1977	10	45	34	11
	Change	+3	+25	+1	-29
Oklahoma	1963	10	20	30	40
	1977	11	37	41	11
	Change	+1	+17	+11	-29
Texas	1963	3	12	45	40
	1977	13	23	46	18
	Change	+10	+11	+1	-22

[1] From Pendleton and Schmude (1979, 240).

Table 11. Average Annual Herbage and Browse Production and Area by Productivity Class of Range Ecosystems[1/]

Ecosystem	Average production, lb/a	Area 1000 a	Area (1000 a) by productivity class (lb/a) ≥5000	3000-4999	1000-2999	<1000
Plains grasslands	1,016	175,239	0	1,826	80,595	92,818
Prairie	3,318	41,186	1,985	9,692	29,509	0
Shinnery	1,870	4,726	8	1,689	385	2,644
Texas savanna	2,142	28,429	0	5,502	21,610	1,317

[1/] Data from USDA Forest Service (1980, 226). Productivity refers to peak standing crop.

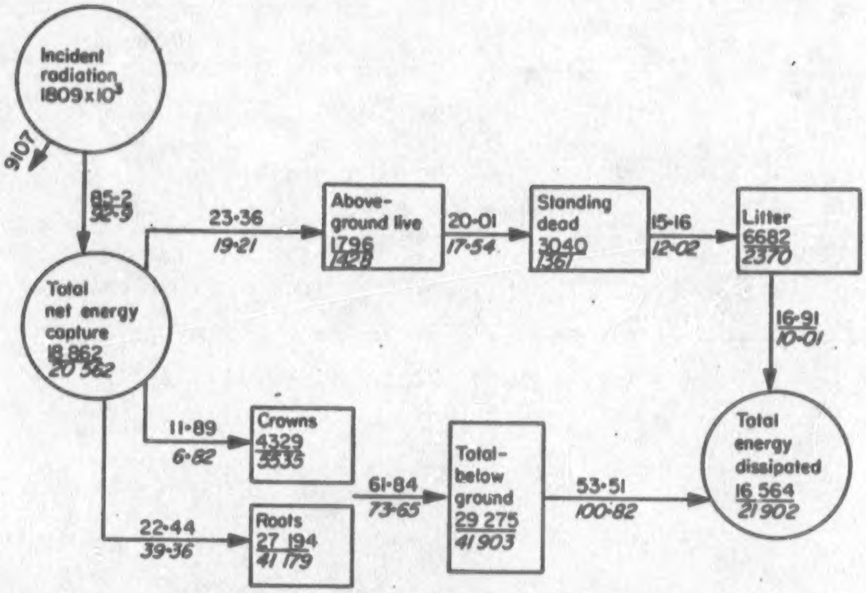

Incident radiation 1809 x 10³
9107
85·2
92·9
Total net energy capture
18 862
20 562
23·36
19·21
Above-ground live
1796
1428
20·01
17·54
Standing dead
3040
1361
15·16
12·02
Litter
6682
2370
16·91
10·01
11·89
6·82
Crowns
4329
3535
22·44
39·36
Roots
27 194
41 179
61·84
73·65
Total-below ground
29 275
41 903
53·51
100·82
Total energy dissipated
16 564
21 902

Figure 31. Diagram of energy flow through the producer system of the mixed-grass prairie ecosystem (Dickinson, Cottonwood and Hays sites) during the growing season. Numbers in square boxes are the mean standing crop (kJ m^{-2}) of the primary producer compartments; numbers in circular boxes are energy inputs and outputs (kJ m^{-2}) to the system; numbers on the arrows are flow rates in kJ m^{-2} day^{-1}. Values in roman are for the ungrazed treatment and values in italics are for the grazed treatment. (The energy contents of crowns and roots do not sum to the value of the total below-ground figures since roots and crowns were not separated at all sites.) To convert kJ m^{-2} to pounds per acre of over dry organic matter multiply by 0.53 for shoots, 0.49 for crown and 0.45 for roots (219).

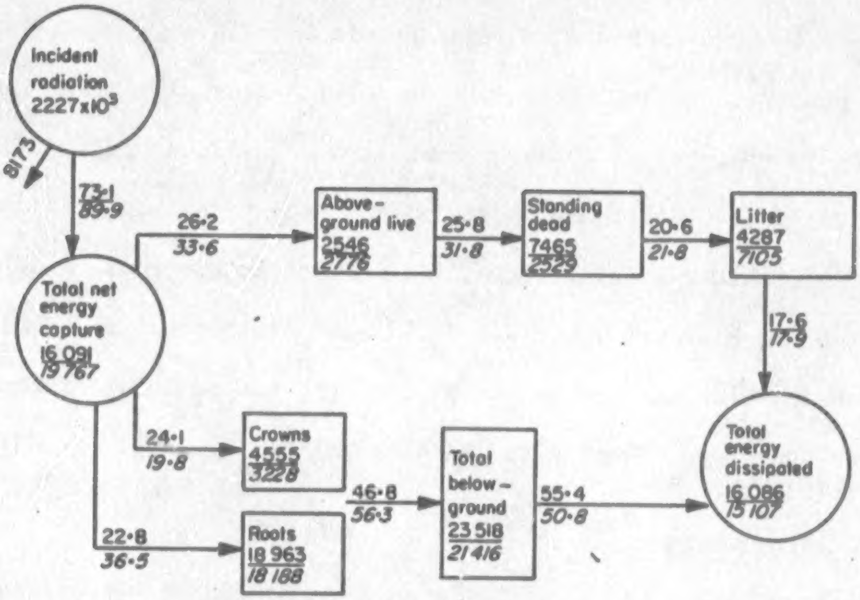

Incident radiation 2227x10³
8173
73·1
89·9
Total net energy capture
16 091
19 767
26·2
33·6
Above-ground live
2546
2776
25·8
31·8
Standing dead
7465
2529
20·6
21·8
Litter
4287
7105
17·6
17·9
24·1
19·8
Crowns
4555
3228
22·8
36·5
Roots
18 963
18 188
46·8
56·3
Total below-ground
23 518
21 416
55·4
50·8
Total energy dissipated
16 086
15 107

Figure 32. Diagram of energy flow through the producer system of the tallgrass prairie ecosystem (Osage site) during the growing season. See Figure 31 for explanation (219).

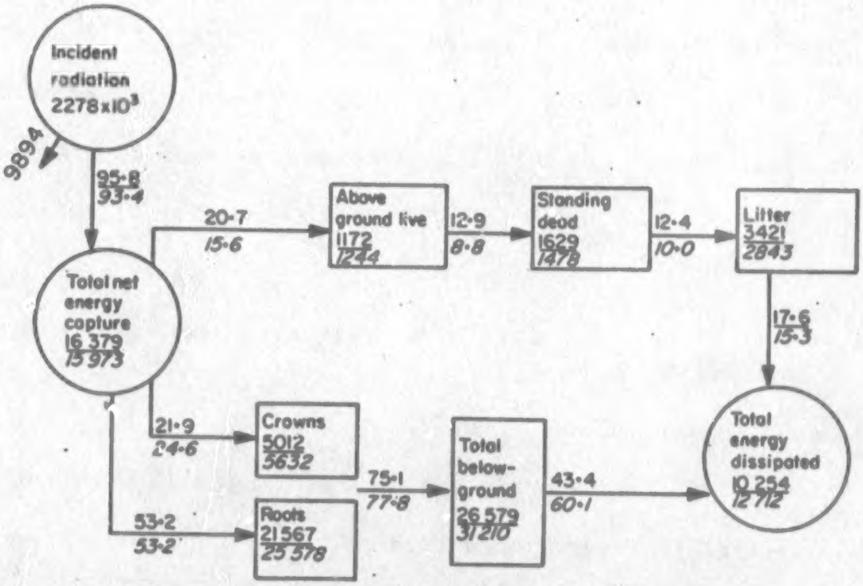

Incident radiation 2278x10³
9894
95·8
93·4
Total net energy capture
16 379
15 973
20·7
15·6
Above ground live
1172
1244
12·9
8·8
Standing dead
1629
1478
12·4
10·0
Litter
3421
2843
17·6
15·3
21·9
24·6
Crowns
5012
3632
53·2
53·2
Roots
21 567
25 578
75·1
77·8
Total below-ground
26 579
31 210
43·4
60·1
Total energy dissipated
10 254
12 712

Figure 33. Diagram of energy flow through the producer system of the shortgrass prairie ecosystem (Pawnee and Pantex sites) during the growing season. See Figure 31 for explanation (219).

4.3.3 Brush Infestation

Since the increase or invasion of brush is a good index of range productivity and quality, the Soil Conservation Service Brush Inventory on the Non-federal Lands is of interest (383). Brush is a significant problem on the rangelands for all of the Great Plains states with the exception of Nebraska and South Dakota (Table 12) and is especially severe in portions of Oklahoma, Texas, New Mexico and Missouri (Fig. 34, 383). The brush problem is getting significantly worse in Oklahoma, Kansas and New Mexico, but is being treated effectively in Texas, Colorado, Wyoming and Missouri (Table 12, Fig. 35, 383).

4.3.4 Soil Erosion

Soil erosion is also an index of condition of rangelands. Distribution of states on the basis of sheet and rill erosion (Fig. 36, 383) was similar to the distribution of states in range condition. Wind erosion was most serious also in Texas and New Mexico. However, these were data calculated from the Universal Soil Loss Equation which has been found to be unreliable on rangelands (230). As expected, both wind and water erosion were most important on the erosion and salinity subclasses, especially in Land Capability Classes IV, VI and VII.

4.4 Rangeland Uses

4.4.1 Overview of Uses

A list of the resources and uses of range ecosystems of the Great Plains, the extent of their development in relation to potential and the potential for importance in the Great Plains and in the United States is shown in Table 13. Rangeland resources are very diverse and very important. However, about 95% of the rangelands of the Great Plains are in private ownership (Table 7). Many

Table 12. Acreage of Brush, Percentage of Area of Brush in Different Density Classes, Percentage Change in Density 1963-73, and Percentage Grazing Land Covered by Brush in the Great Plains States[1]

State	Acreage, 1973, 1000 a	Brush density						Grazing land covered by brush, %
		Sparse		Medium		Dense		
		%	change, %	%	change, %	%	change, %	
Montana	15,000	45	-1	25	-1	30	-1	36
Wyoming	22,700	66	-3	12	+16	22	-24	84
Colorado	7,927	30	+87	40	+87	30	-57	31
New Mexico	23,815	50	-14	30	+12	20	+39	56
North Dakota	7,000	82	-t	11	+1	6	+5	58
South Dakota	107	85	+3	14	+3	1	+3	4
Nebraska	300	22	-13	53	-14	25	-35	1
Kansas	4,100	35	-t	25	+14	40	+30	22
Oklahoma	11,016	5	-38	35	-14	60	+85	47
Texas	91,825	24	+136	33	+8	43	-30	80

[1] Data from U.S.D.A. (383).
"...brush is defined as woody half-shrubs, shrubs and trees that invade land on which they are not part of the potential natural (climax) plant community or occur in amounts significantly in excess of that which is natural to the site" (383, p. 3-48).

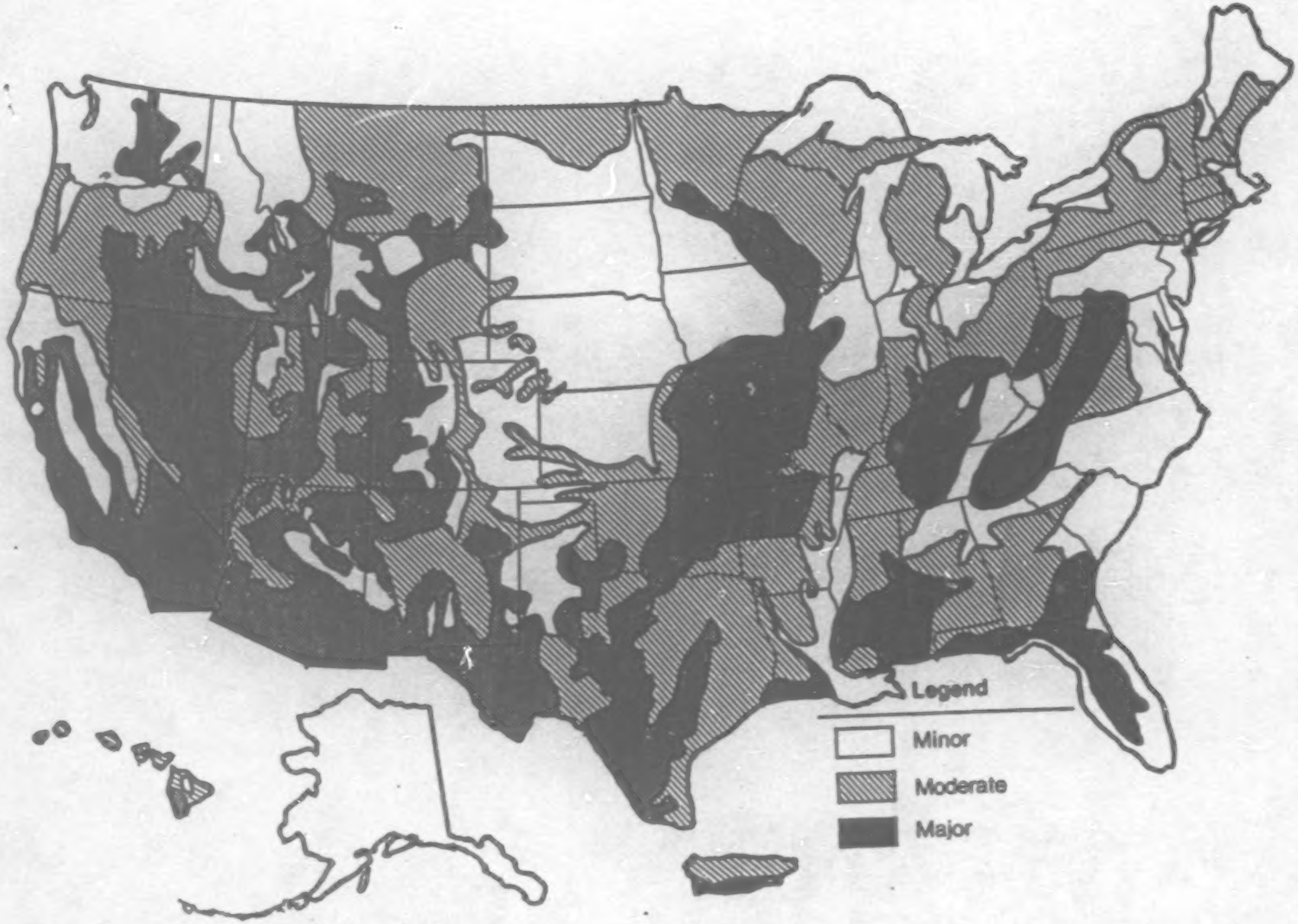

Legend
Minor
Moderate
Major

Figure 34. Brush distribution and density (383).

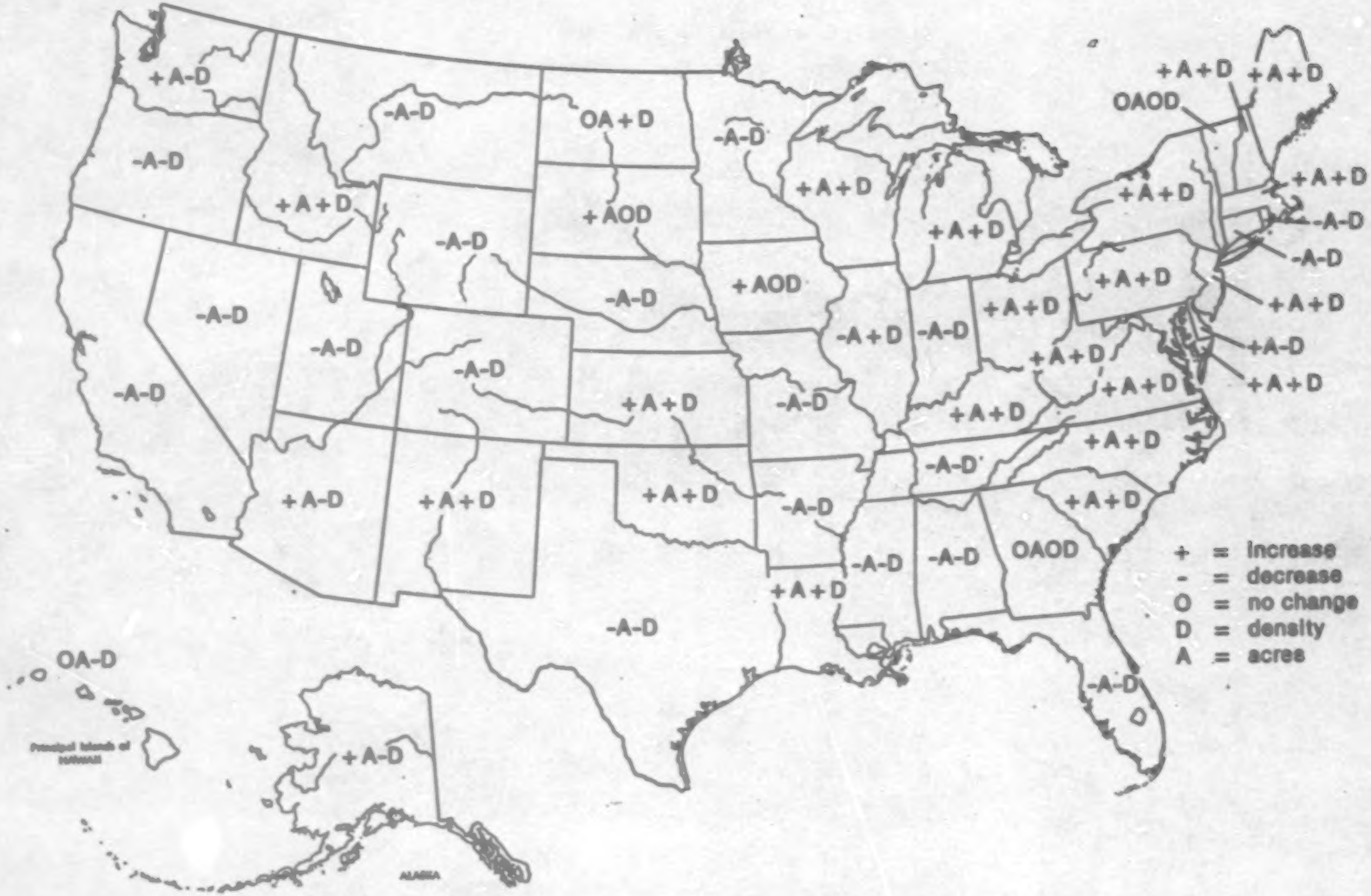
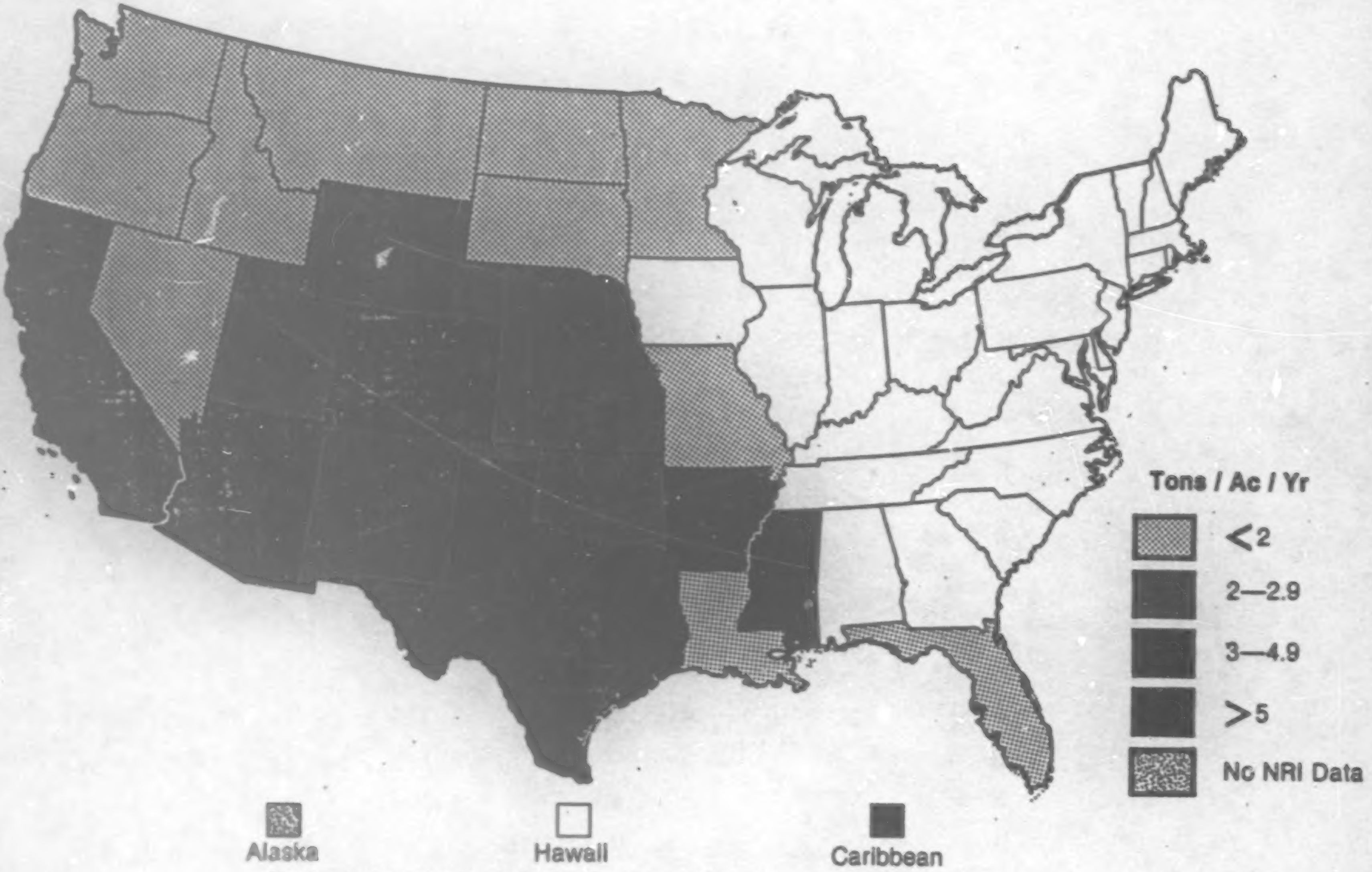

+A-D
-A-D
-A-D
+A+D
-A-D
-A-D
-A-D
+A-D
-A-D
-A-D
+A+D
OA+D
+AOD
-A-D
+A+D
+A+D
-A-D
-A-D
+AOD
-A-D
-A-D
+A+D
-A-D
+A+D
-A+D
-A-D
+A+D
-A-D
-A-D
+A+D
+A+D
+A+D
-A-D
+A+D
+A+D
+A+D
OAOD
-A-D
+A+D
+A+D
OAOD
+A+D
+A-D
-A-D
+A+D
+A-D
+A+D
OA-D
Principal Islands of HAWAII
+A-D
ALASKA
+ = increase
- = decrease
O = no change
D = density
A = acres

Figure 35. Trend in density and acres of brush on non-federal rangeland, native pasture, and pastureland (383).


Tons / Ac / Yr
<2
2—2.9
3—4.9
>5
No NRI Data
Alaska
Hawaii
Caribbean

Unshaded states have insignificant amounts of rangeland

Figure 36. Sheet and rill erosion on non-federal rangeland (383).

Table 13. Resources and Uses of Range Ecosystems of the Great Plains[1]

Resources and uses	Development extent[2]	Potential[3]	
		Great Plains	United States
I. Site Constants			
A. Geological materials and soils			
1. Minerals			
a. Surface mining			
1) Metallic minerals	2	3	2
2) Non-metallic minerals (sand, gravel, clay, rock, gypsum, barite, phosphate, pottash, cement)	3	3	2
3) Fuel minerals (coal, oil shale, uranium)	2	3	3
b. Surbsurface mining			
1) Metallic minerals	2	2	1
2) Fuel minerals (oil, natural gas)	2	3	3
2. Ground water (fossil water)			
1) Mining water for various uses, see IV	3	3	3
2) Ground water heat pumps	1	1	1
3) Hydrothermal power	1	2	1
3. Land and space			
a. Conversion to cropland and introduced pasture			
1) Dryland crops	3	3	2
2) Irrigated crops	3	3	2
b. Conversion to urban-industrial ecosystems			
1) Transportation corridors			
Railroads, highways, roads, pipelines	3	3	2
Water	1	3	1
Oil	2	1	2
Gas	3	1	3
Coal slurry	1	1	2
Electric transmission lines	1	1	2
Airports	2	2	1
Canals	1	1	1
2) Cities, towns, and industrial areas	2	3	1
3) Military reservations and outposts, missile sites, etc.	2	2	2
4) Solar panel locations	1	2	2
5) Waste disposal (radioactive, pollutants, various wastes)	1	3	1

Table 13. Continued

Resources and uses	Development extent[2]	Potential[3] Great Plains	Potential[3] United States
II. Driving Variables			
A. Solar power	1	3	2
B. Wind power	1	3	2
III. Vegetation			
A. Human food (gathering)	1	1	1
B. Harvested animal feed	3	2	1
C. Fuels from biomass: primarily applicable to Texas savanna, Shinnery, Open forests, and brush-infested ranges (300)			
1. Combustion (producing CO_2, water, ash, heat, steam, electricity)	1	1	1
2. Gasification (producing char, oil, gas, such as CO, C_2H_4, H_2)	1	2	1
3. Gasification + catalytic synthesis (producing methanol and hydrocarbons)	1	2	1
4. Anaerobic digestion (producing methane, CO_2)	1	3	2
5. Yeast fermentation producing ethanol plus CO_2 requires conversion to cropland	-	-	-
6. Extracted hydrocarbon - requires conversion to cropland (301)	-	-	-
D. Chemicals, including pharmaceuticals	1	1	1
E. Germ plasm for genetic improvement of pasture and crop plants	1	3	2
F. Protection of endangered and threatened plant species (215, 260)	-	-	-
1. Federal: 1, *Zizania texana* (endangered)			
2. States: 420 species plus 23 extinct listed by states (MT, 18; WY, 24 + 2 ext.; CO, 64 + 4 ext.; NM, 56 + 1 ext.; ND, 3; SD, 2; NE, 4; KS, 3; OK 21 + 1 ext.; TX, 225 + 15 ext.)			
IV. Hydrologic Cycle (natural water sources: wetlands, springs, streams and rechargeable groundwater; harvested water: small impoundments, dugouts, rainfall catchments, large impoundments)			
A. Water for range ecosystems			
1. Grazing food web	3	3	3
2. Fish habitat	3	2	2
3. Recreation (see V, A, 2)	1	3	2
B. Water for cropland (irrigation)	3	3	3
C. Water for urban-industrial ecosystems			
1. Domestic water	2	3	2
2. Manufacturing	2	3	2

Table 13. Continued

Resources and uses	Development extent[2]	Potential[3] Great Plains	United States
3. Mining, mineral transport and processing	1	3	2
4. Hydroelectric power	2	3	2
5. Navigation	2	2	2
6. Saline water-solar power	1	2	1
D. Decontamination of air pollution from urban-industrial ecosystems (375)	-	-	-
V. Total Ecosystem			
A. Activities			
1. Livestock grazing	3	3	2
2. Recreation			
a. Developed			
1) Camp grounds	2	2	1
2) Guest lodges	1	2	1
3) Vacation homes	1	2	1
4) Ski lifts and lodges	1	2	1
b. Undeveloped			
1) Consumptive			
a) Hunting	2	3	1
b) Fishing	1	2	1
c) Gathering (rocks, plants, food, etc.)	1	1	1
d) Off-road vehicle use	1	1	1
2) Nonconsumptive			
a) Land			
(1) Wilderness	3	1	2
(2) Parks	2	2	2
(3) Sight-seeing, photography, backpacking, hiking, horseback riding, etc.	2	3	2
b) Water			
(1) Wild and scenic rivers	3	1	1
(2) Swimming, boating, etc.	2	3	1
c) Snow and ice: skiing, sledding, ice skating, snowmobiling, etc.	2	3	1
3. Research and education			
a. Structure, function and management of range ecosystems			
1) Research laboratories	1	3	2
2) Teaching laboratories	1	3	2
b. Germ plasm for animal domestication and genetic improvement	1	2	2
c. Protection of endangered, threatened and sensitive species (215, 88)	-	-	-
1) Federally listed			

Table 13. Continued

Resources and uses	Development extent[2]	Potential[3]	
		Great Plains	United States
a) 4 birds: whooping crane, E; Bald eagle, E, T; American peregrine falcon, E; Atwater's greater prairie chicken, E			
b) 2 mammals: Black-footed ferret, E; and swift fox, E			
2) Additional state-listed: 12 reptiles, 9 amphibians, 25 birds, 18 fish and 22 mammals			
3) Additional Forest Service-designated as sensitive: 45 birds, 17 mammals and 14 fish			
d. Paleontology	1	2	2
e. Archeology	1	2	2
f. Historical sites	1	2	2
4. Human habitat	3	3	1
B. Businesses directly using range ecosystems			
1. Ranches	3	3	3
2. Tourist businesses (guest lodges, guide services, etc.)	1	3	2
3. Mining companies	2	3	2
4. Energy development companies	1	3	2
5. Utility companies	2	3	2
6. Universities and research organizations	2	3	2

---

[1] Much of the material in this table has been drawn from compilations in 226 as well as other sources. The authors are responsible for various additions, as well as organization and evaluation.

[2] Extent of development in relation to potential:

1. None or very little
2. Significant
3. Substantial, approaching the potential

[3] Potential for development to have an impact on business income or quality of life in the region or the nation:

1. Little or no impact
2. Moderate impact
3. Large impact

of the potential uses are difficult to exploit economically. If these uses are to be fully developed for the benefit of the nation, methods and institutions must be developed for incorporating these uses into the economic structure of the ranch business. For example, essentially all ranchers love wildlife, yet, if there is no economic incentive to manage for wildlife habitat, then most of the wildlife habitat will be the by-product of management for other uses.

Livestock production is the most important use of the rangelands of the Great Plains and is now, and is likely to remain, the major source of income for Great Plains ranches for the foreseeable future.

Comments are made below on certain uses in order of their appearance in Table 13.

4.4.2 Minerals

The distribution of metallic minerals and some of the fuel minerals are shown in Fig. 37 (226), 38 (383), 39 (226), and 40 (382).

4.4.3 Water Resources

Water resource regions are shown in Fig. 41 (226). A very large amount of area of different water resources are available in the Great Plains states (Table 14). Limited water quality is a problem in the streams of the southern Prairie, southern Plains grasslands and the southern Texas savanna (Fig. 42, 383). Adequate water supplies for livestock are a very great problem throughout the drier part of the region (Fig. 43, 383) in spite of the large surface area of small reservoirs (Table 14).

Surprisingly, part of the northern Plains grasslands and much of the Prairie are important wetland areas (Fig. 44, 389), supporting large numbers of breeding ducks (Fig. 45, 382). Many of these, however, are in need of protection (Fig. 46, 226).

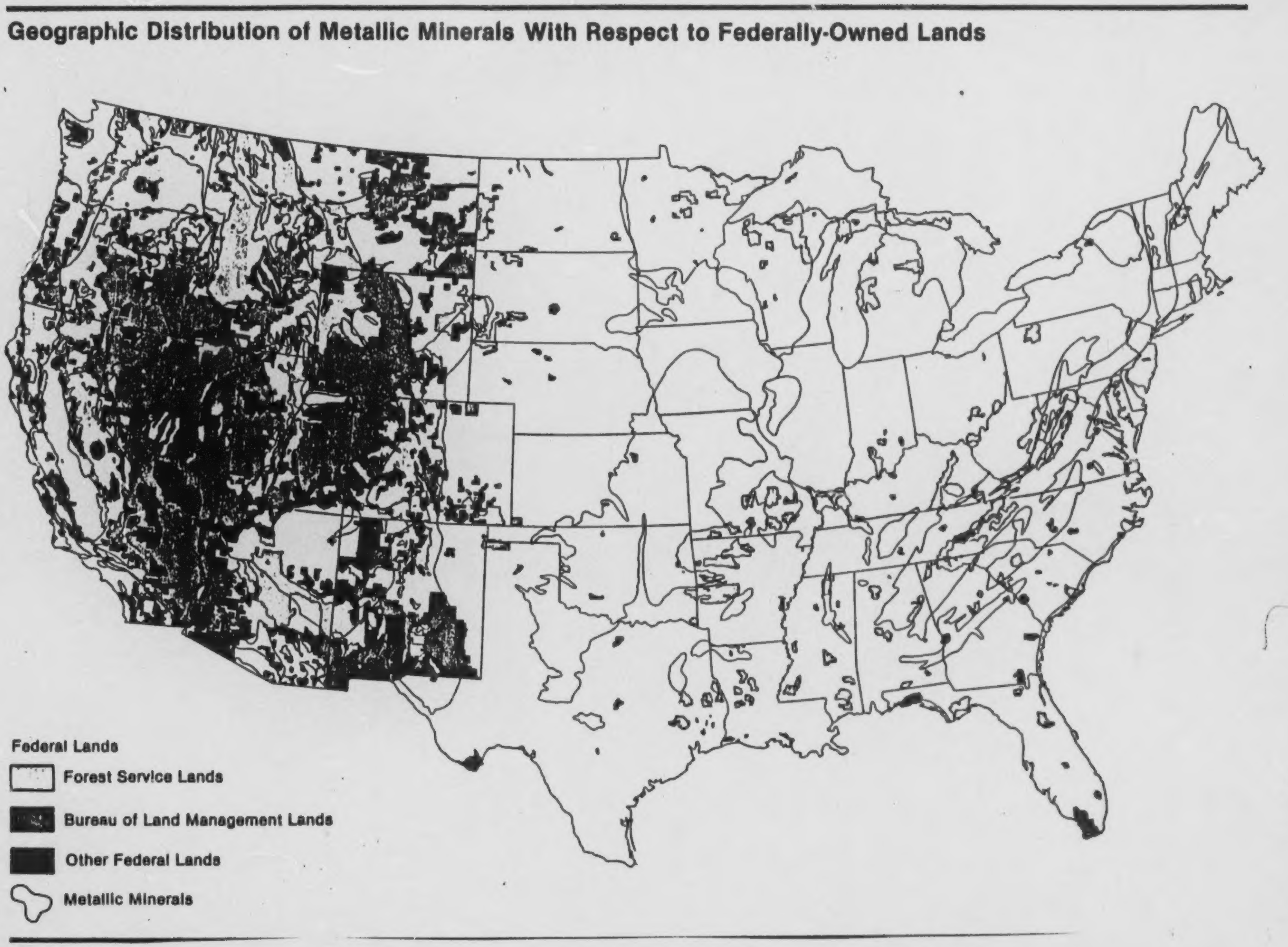
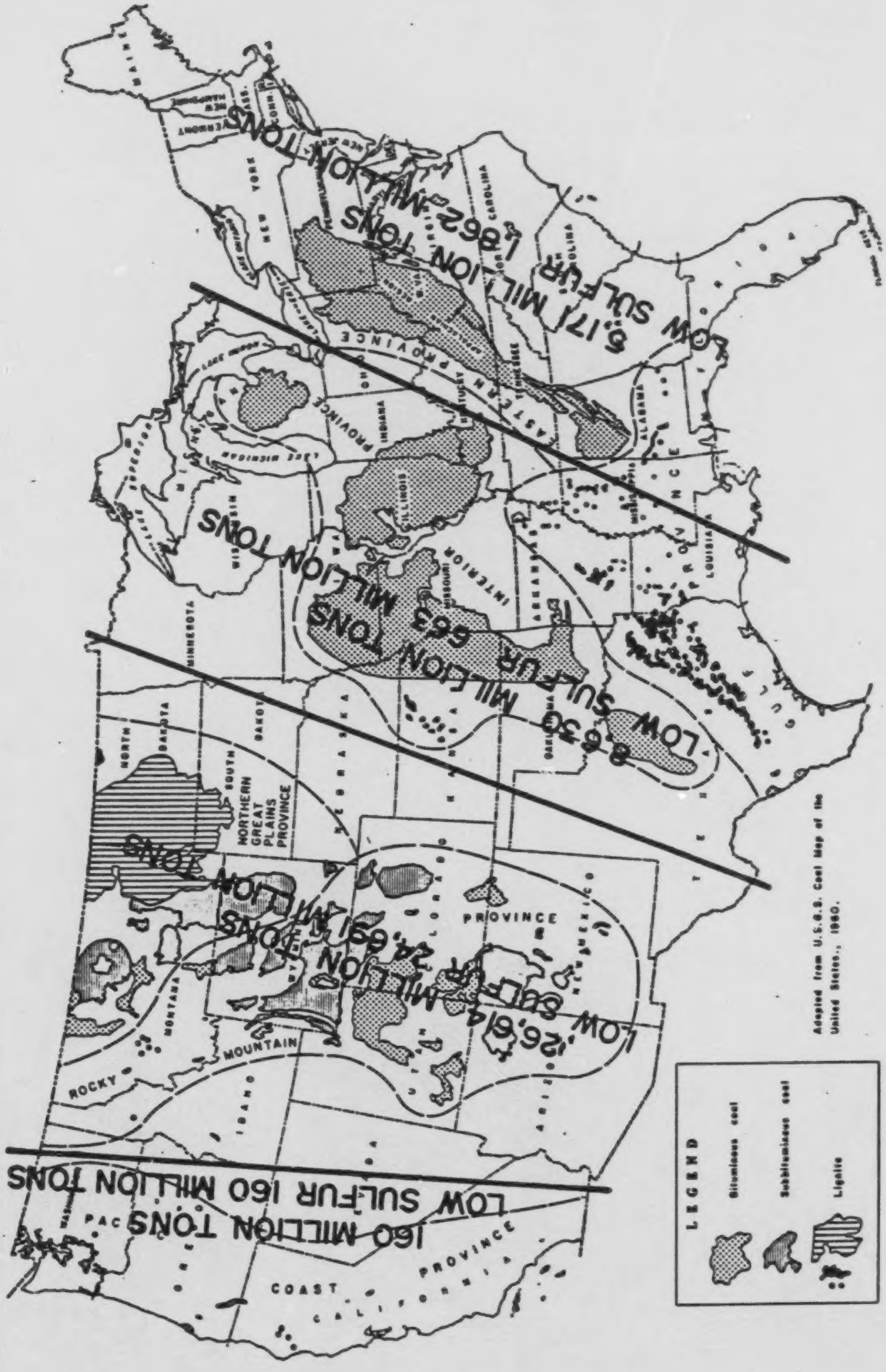

Geographic Distribution of Metallic Minerals With Respect to Federally-Owned Lands
Federal Lands
Forest Service Lands
Bureau of Land Management Lands
Other Federal Lands
Metallic Minerals

Figure 37. Geographic distribution of metallic minerals with respect to federally-owned lands (226).


LOW SULFUR 160 MILLION TONS
160 MILLION TONS
LOW SULFUR 24,691 MILLION TONS
126,614 MILLION TONS
LOW SULFUR 663 MILLION TONS
8,630 MILLION TONS
LOW SULFUR 1,862 MILLION TONS
5,171 MILLION TONS
PACIFIC COAST PROVINCE
ROCKY MOUNTAIN PROVINCE
NORTHERN GREAT PLAINS PROVINCE
INTERIOR PROVINCE
EASTERN PROVINCE
GULF PROVINCE
LEGEND
Bituminous coal
Subbituminous coal
Lignite

Adapted from U.S.G.S. Coal Map of the United States, 1960.

Figure 38. Strippable coal reserves of the conterminous United States, by region (383).

Geographic Distribution of Coal, Oil Shale, and Tar Sands With Respect to Federally Owned Lands

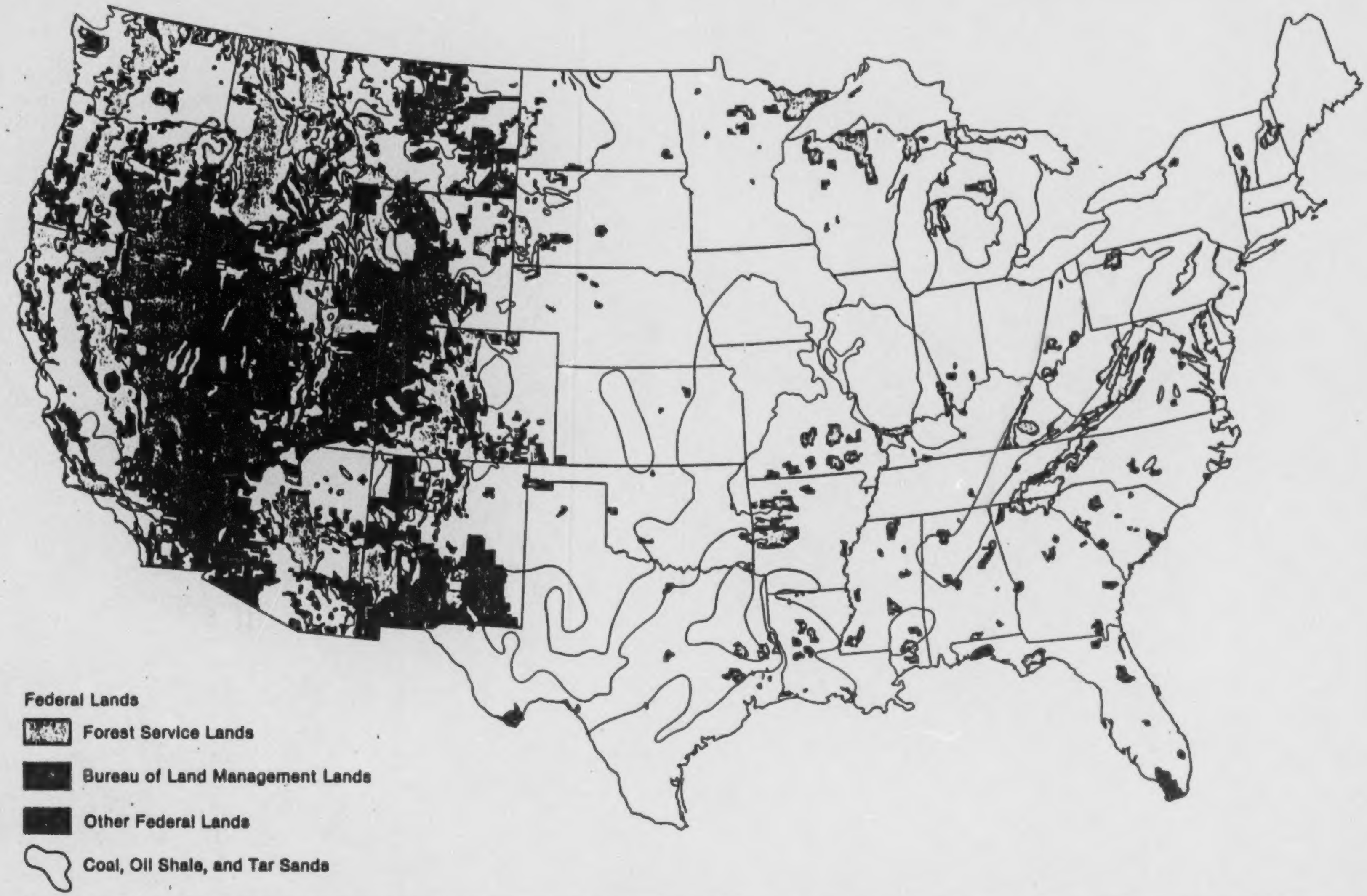

Federal Lands
Forest Service Lands
Bureau of Land Management Lands
Other Federal Lands
Coal, Oil Shale, and Tar Sands

Figure 39. Geographic distribution of coal, oil shale, and tar sands with respect to federally-owned lands (226).

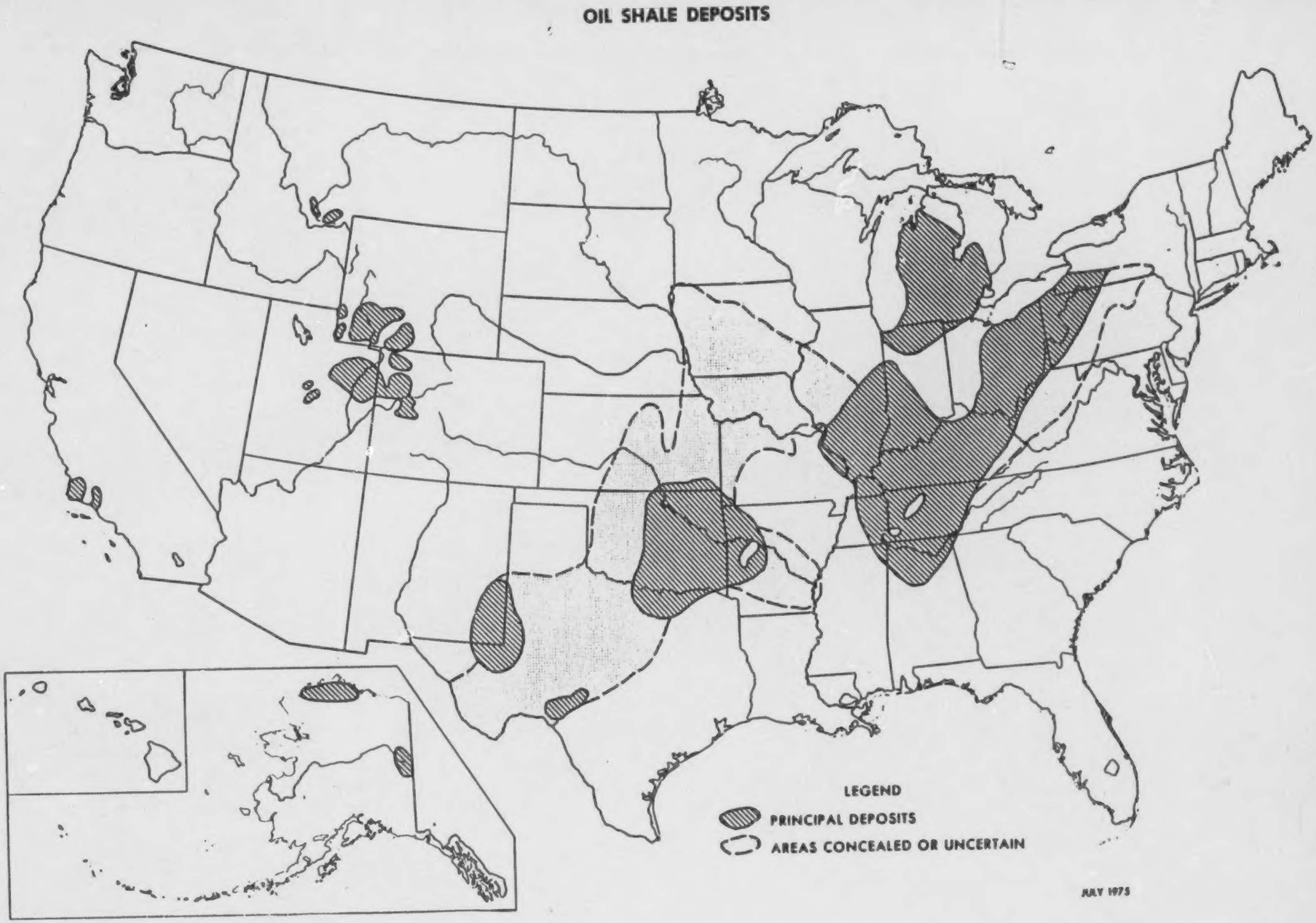

OIL SHALE DEPOSITS
LEGEND
▨ PRINCIPAL DEPOSITS
AREAS CONCEALED OR UNCERTAIN
JULY 1975

Figure 40. Oil shale deposits (382).

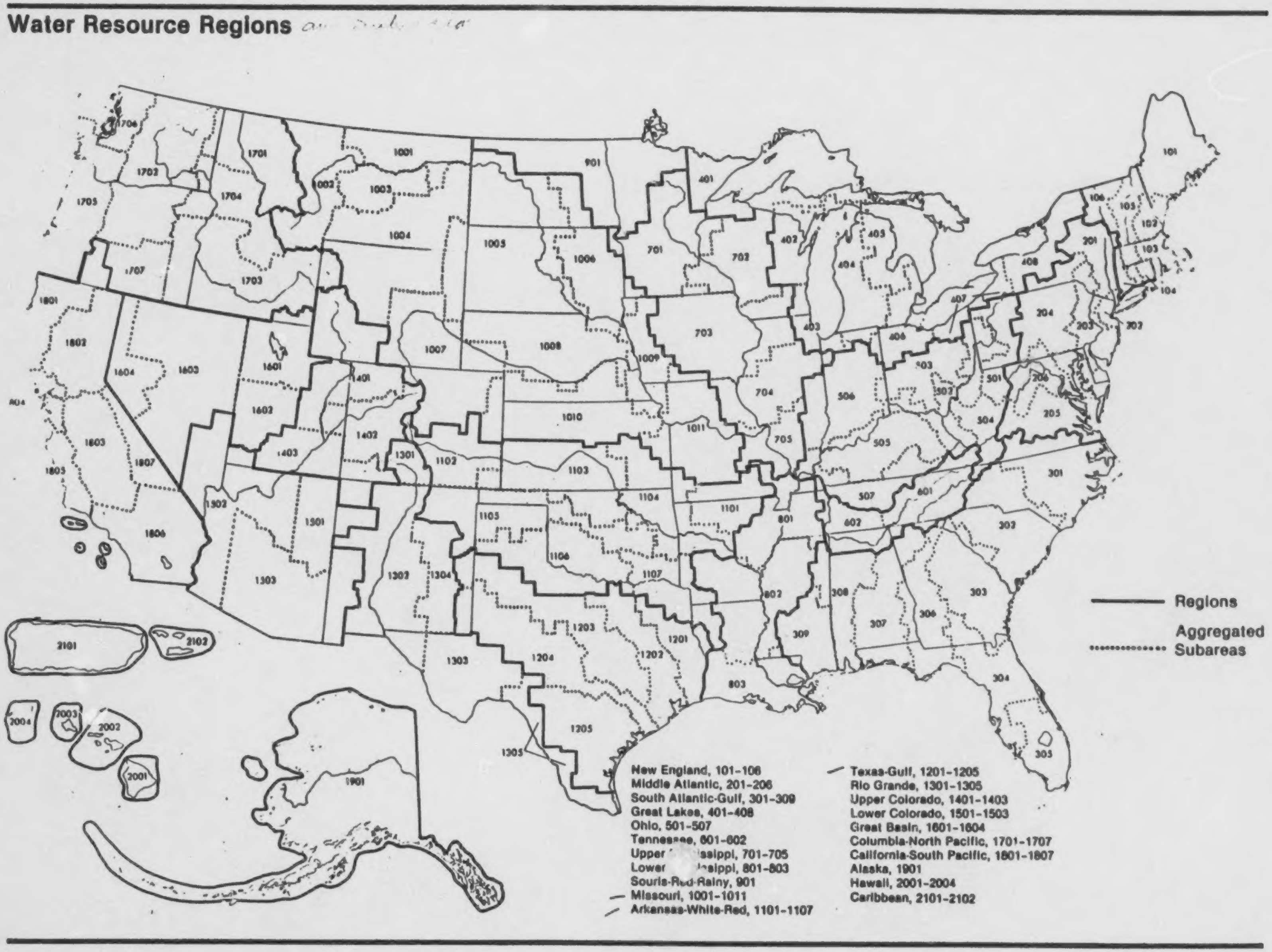

Water Resource Regions
Regions
Aggregated Subareas
New England, 101-106
Middle Atlantic, 201-206
South Atlantic-Gulf, 301-309
Great Lakes, 401-408
Ohio, 501-507
Tennessee, 601-602
Upper [illegible]ssippi, 701-705
Lower [illegible]ssippi, 801-803
Souris-Red-Rainy, 901
Missouri, 1001-1011
Arkansas-White-Red, 1101-1107
Texas-Gulf, 1201-1205
Rio Grande, 1301-1305
Upper Colorado, 1401-1403
Lower Colorado, 1501-1503
Great Basin, 1601-1604
Columbia-North Pacific, 1701-1707
California-South Pacific, 1801-1807
Alaska, 1901
Hawaii, 2001-2004
Caribbean, 2101-2102

Figure 41. Water resource regions and subregions (226).

Table 14. Inland Water Surface Areas in the Great Plains States[1]

	Inland waters				
		Large	Small		
State	Total	Rivers >1/8 mi wide, water >40 a	Streams <1/8 mi wide	2-40 a	<2 a
Montana	1,289	1,040	134	97	18
Wyoming	622	525	51	40	6
Colorado	447	311	73	54	9
New Mexico	201	149	41	6	5
North Dakota	1,304	923	90	273	18
South Dakota	959	743	49	137	30
Nebraska	623	451	88	57	27
Kansas	588	295	134	93	66
Oklahoma	1,140	828	85	108	119
Texas	4,000	3,315	276	223	186
Total	11,173	8,580	1,021	1,088	484

---

[1] Data from U.S.D.A. (383).

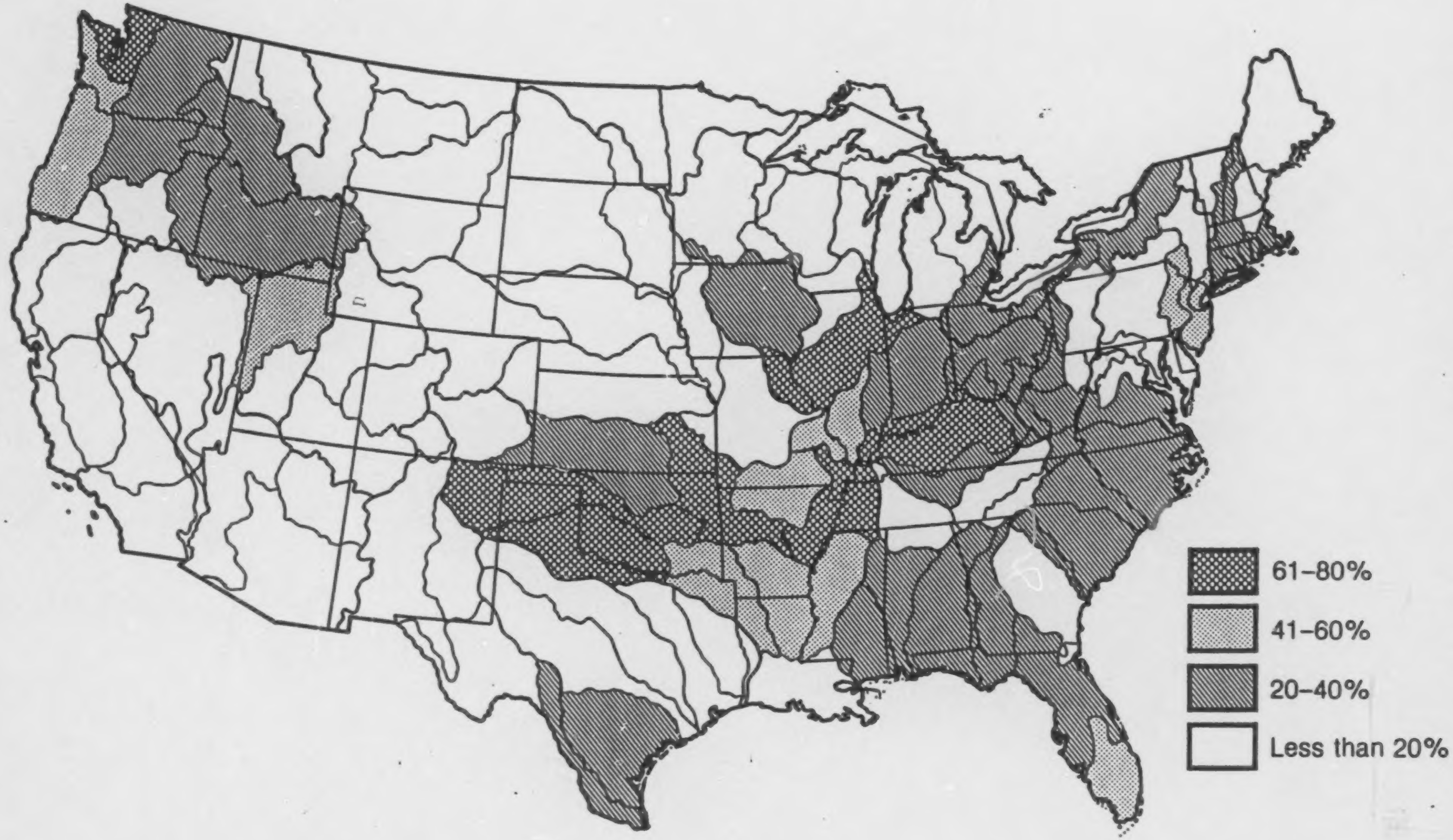

61–80%
41–60%
20–40%
Less than 20%

Figure 42. Percentage of streams having limited water quality (383).

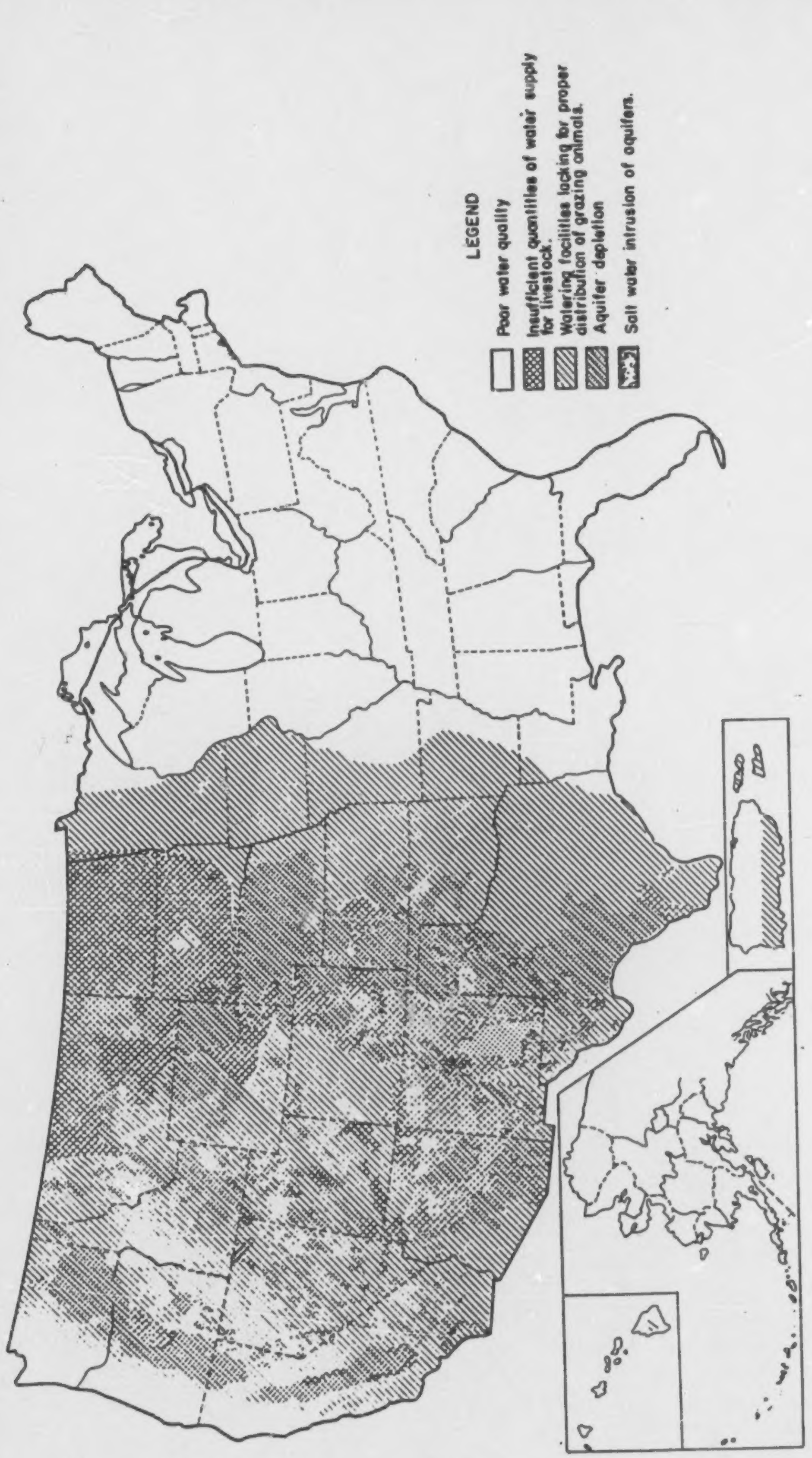

LEGEND
Poor water quality
Insufficient quantities of water supply for livestock.
Watering facilities lacking for proper distribution of grazing animals.
Aquifer depletion
Salt water intrusion of aquifers.

Figure 43. Location of severe livestock watering problems (383).

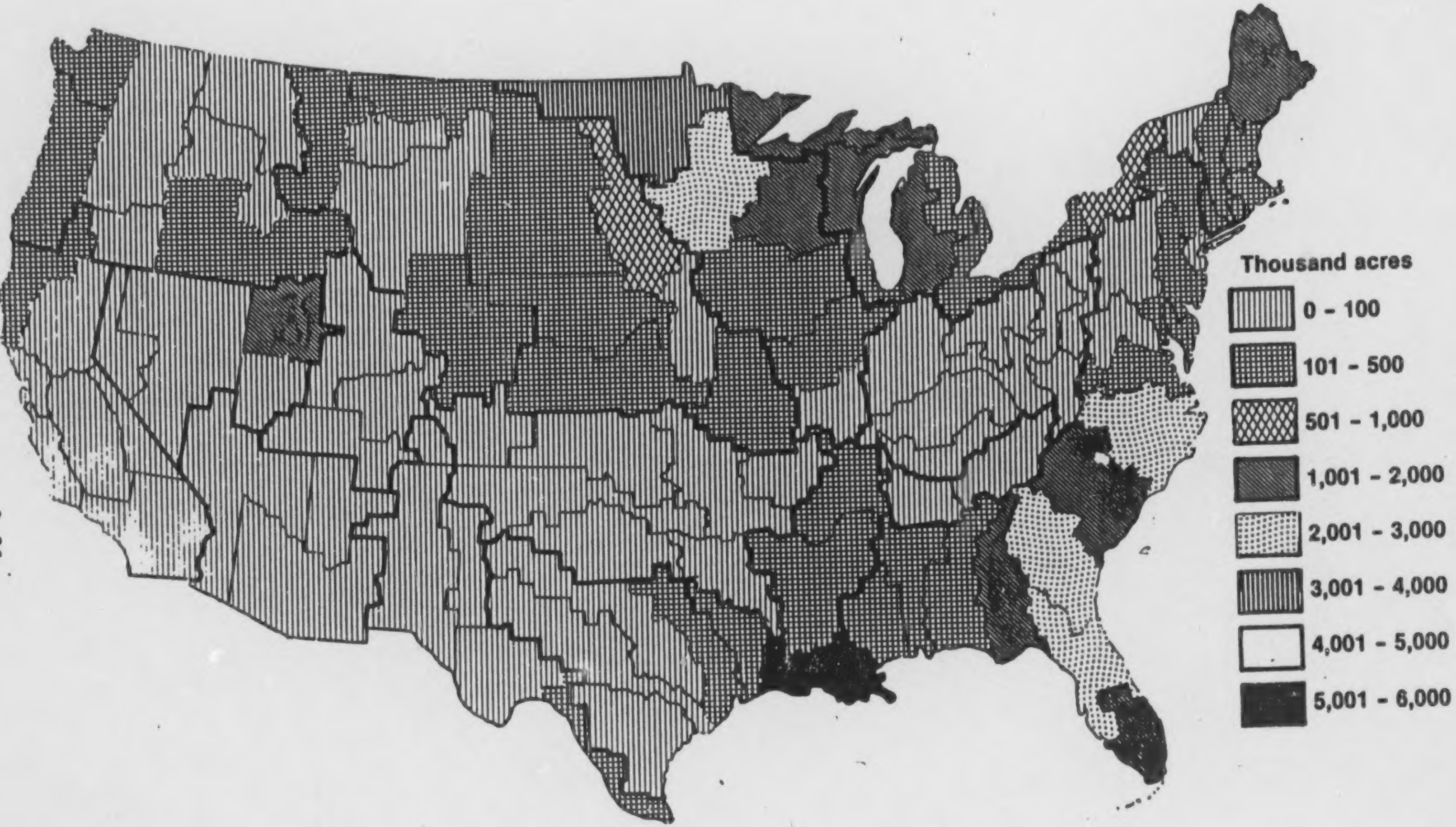

Thousand acres
0 - 100
101 - 500
501 - 1,000
1,001 - 2,000
2,001 - 3,000
3,001 - 4,000
4,001 - 5,000
5,001 - 6,000

Figure 44. Total acreage in wetland types 3-20, by ASA (389).

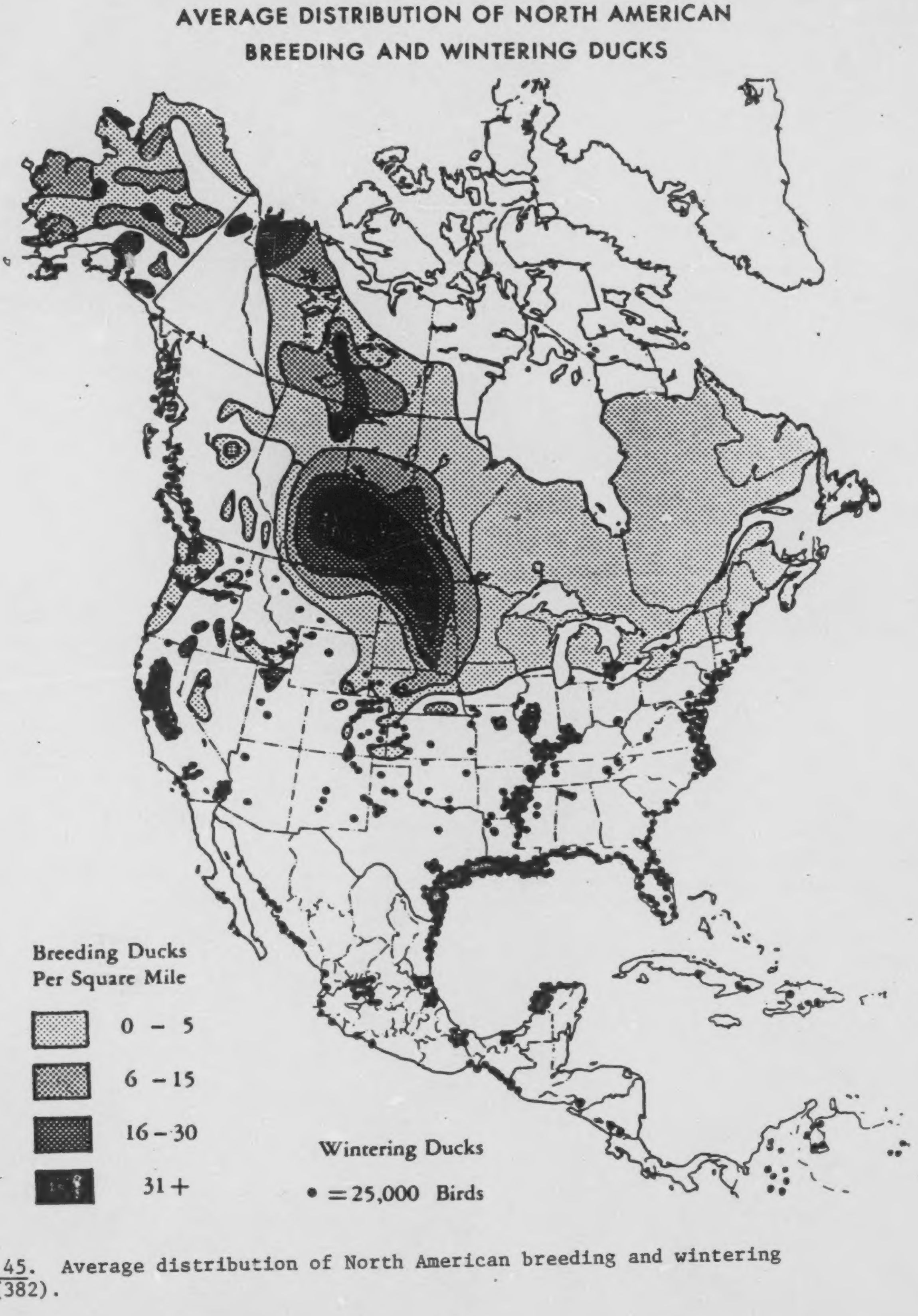

AVERAGE DISTRIBUTION OF NORTH AMERICAN BREEDING AND WINTERING DUCKS
Breeding Ducks Per Square Mile
0 - 5
6 - 15
16 - 30
31 +
Wintering Ducks
● = 25,000 Birds

Figure 45. Average distribution of North American breeding and wintering ducks (382).

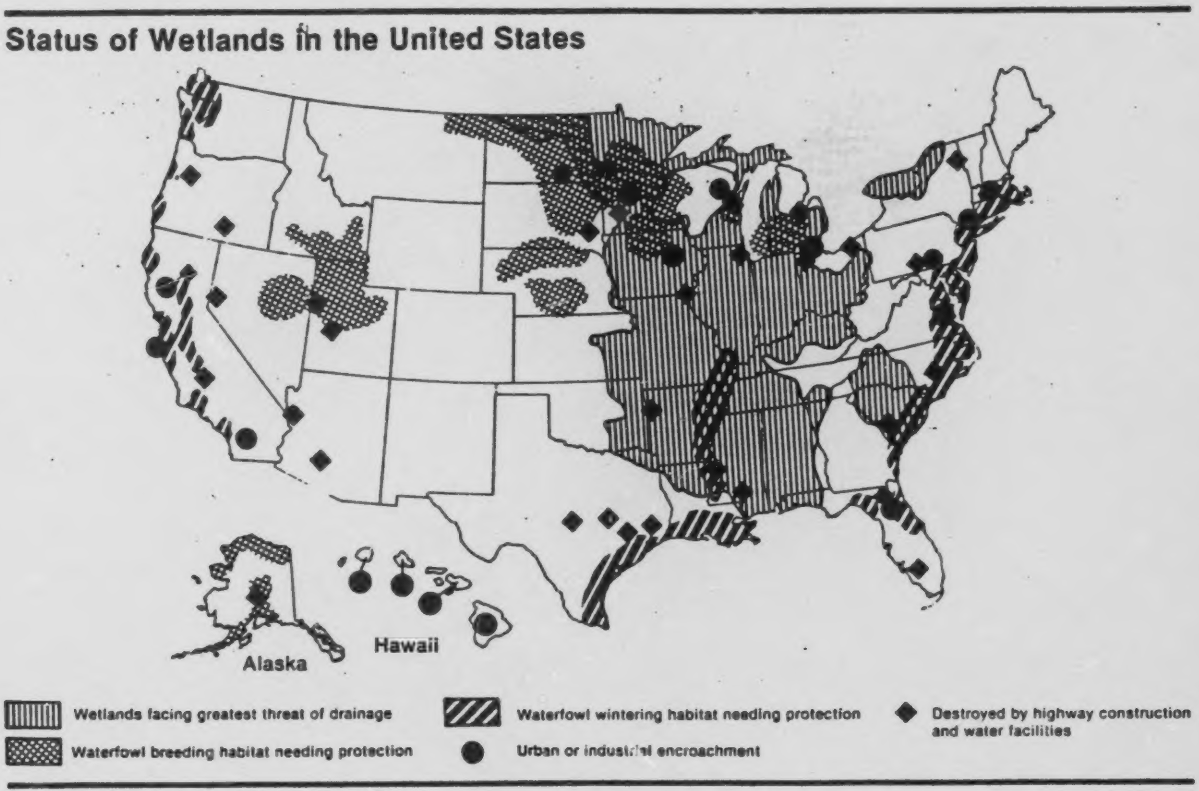

Status of Wetlands in the United States
Alaska
Hawaii
▥ Wetlands facing greatest threat of drainage
▩ Waterfowl breeding habitat needing protection
▨ Waterfowl wintering habitat needing protection
● Urban or industrial encroachment
◆ Destroyed by highway construction and water facilities

Figure 46. Status of wetlands in the United States (226).

Large supplies of groundwater are located in the region (Fig. 47, 226). Irrigation use has been very heavy, especially in the southern and central Plains and is developing rapidly in Nebraska (Fig. 48, 383; Table 15). Extensive mining of fossil water in the Texas Panhandle is exhausting the aquifer and forcing transition to dryland agriculture and possibly to range. The percentage of stream flow devoted to irrigation is expected to decrease (Table 16).

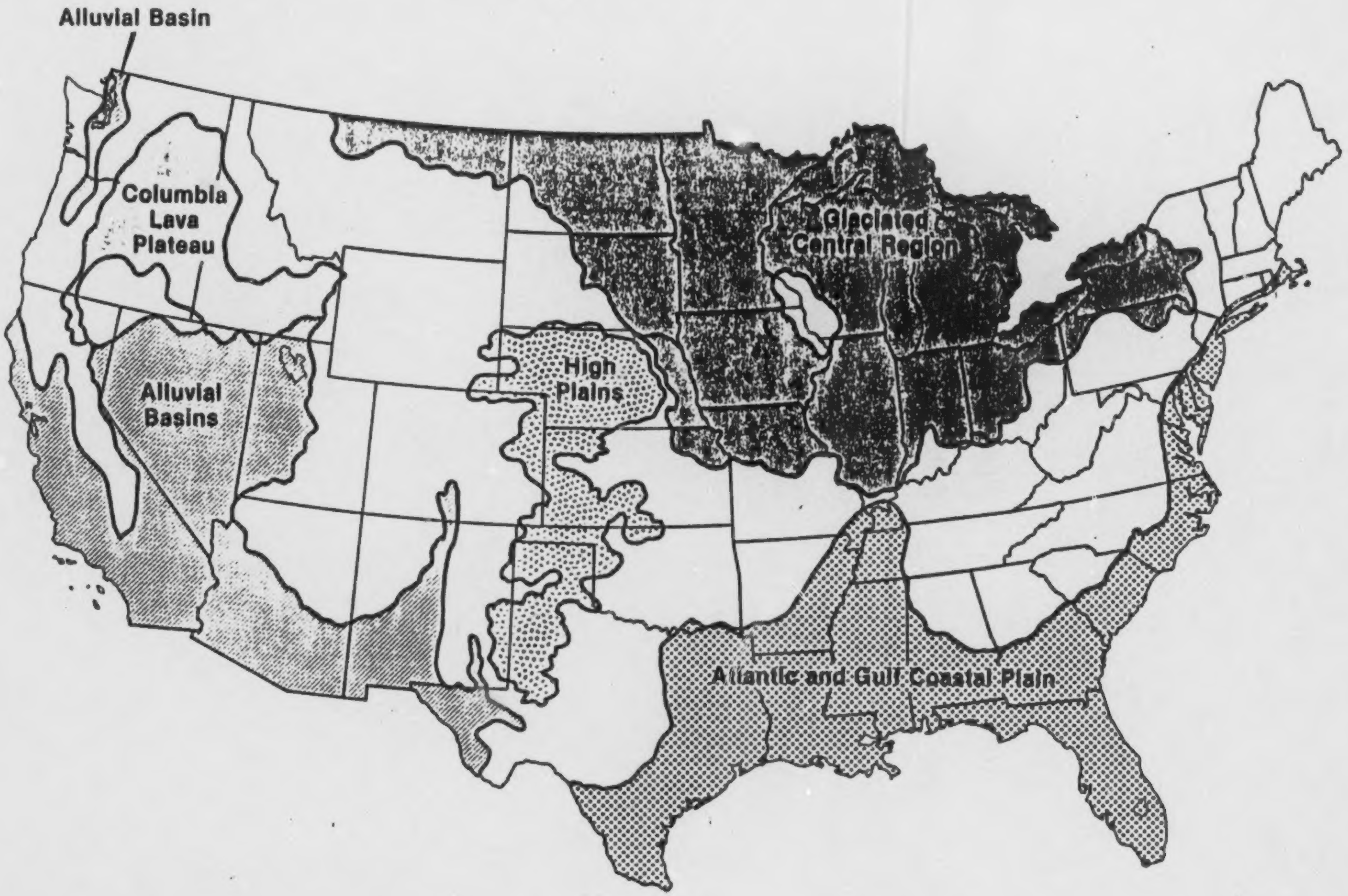
Urban-industrial uses of stream flow from Water Resource Regions draining and crossing the Plains and Prairies are increasing (Table 16). Rather large increases in water use are expected in steam electric cooling and mineral extraction. Use of water from the Madison formation for a slurry pipeline for movement of coal from the northern Great Plains to industrial areas is being strongly contested by Plains residents. The Madison formation is an important source of water in the area for both urban and rural use.

4.4.4 Forage for the Grazing Food Web

The dominant use of forage is for livestock grazing. Average forage production in 1970 was estimated to be 0.31 AUM/a for the Plains grasslands for a total of 50,454,000 Animal Unit Months (AUMs) of grazing (382). Comparable figures for the Prairie were 1.01 AUM/a and 36,814,000 AUMs, for the Texas savanna 0.34 AUM/a and 5,042,000 AUMs, and for the Shinnery 0.23 AUM/a and 456,000 AUMs of grazing. These figures probably are for cattle under seasonlong continuous grazing under existing range condition classes. These can be increased by range improvement and good grazing management, including optimum combinations of grazing animals and good grazing systems. Grazing available for livestock by Ecosystem and Existing Management Level in 1976 is shown in Table 17.

On a national basis, the amount of grazing has declined (Fig. 49, 226), probably due to increased concentrate feeding, which will probably decrease with greater demand for grains as food and with higher grain prices.

Major Areas of Potential Groundwater Development


Alluvial Basin
Columbia Lava Plateau
Alluvial Basins
High Plains
Glaciated Central Region
Atlantic and Gulf Coastal Plain

Regional data not available for Alaska, Hawaii, and Puerto Rico.

Figure 47. Major areas of potential groundwater development (226).

Table 15. Water Resource Subregions of the Great Plains with Consumptive Water Use Exceeding 50% of the Water Supply Which is Available Without Ground Water Mining 90% of the Time[1]

Water resource subregion	Range, % area	Water supply, mgd-1 [2]	Consumptive water use, % supply			Months 1975 use would exceed 90% supply without ground water mining
			1975	1985	2000	
Niobrara-Platte-Loup (1008)	63	6,046	55	69	67	3
Kansas (1010)	36	4,166	93	97	95	3
Arkansas-Cimarron (1103)	33	1,793	113	140	142	4
Canadian (1005)	68	1,991	123	119	121	10
Red-Washita (1106)	56	2,537	90	96	89	6
Brazos (1203)	47	2,703	179	142	114	8
Colorado (1204)	70	2,550	120	104	98	6

[1] Data from USDA Forest Service (1980, 226).
[2] Million gallons per day.

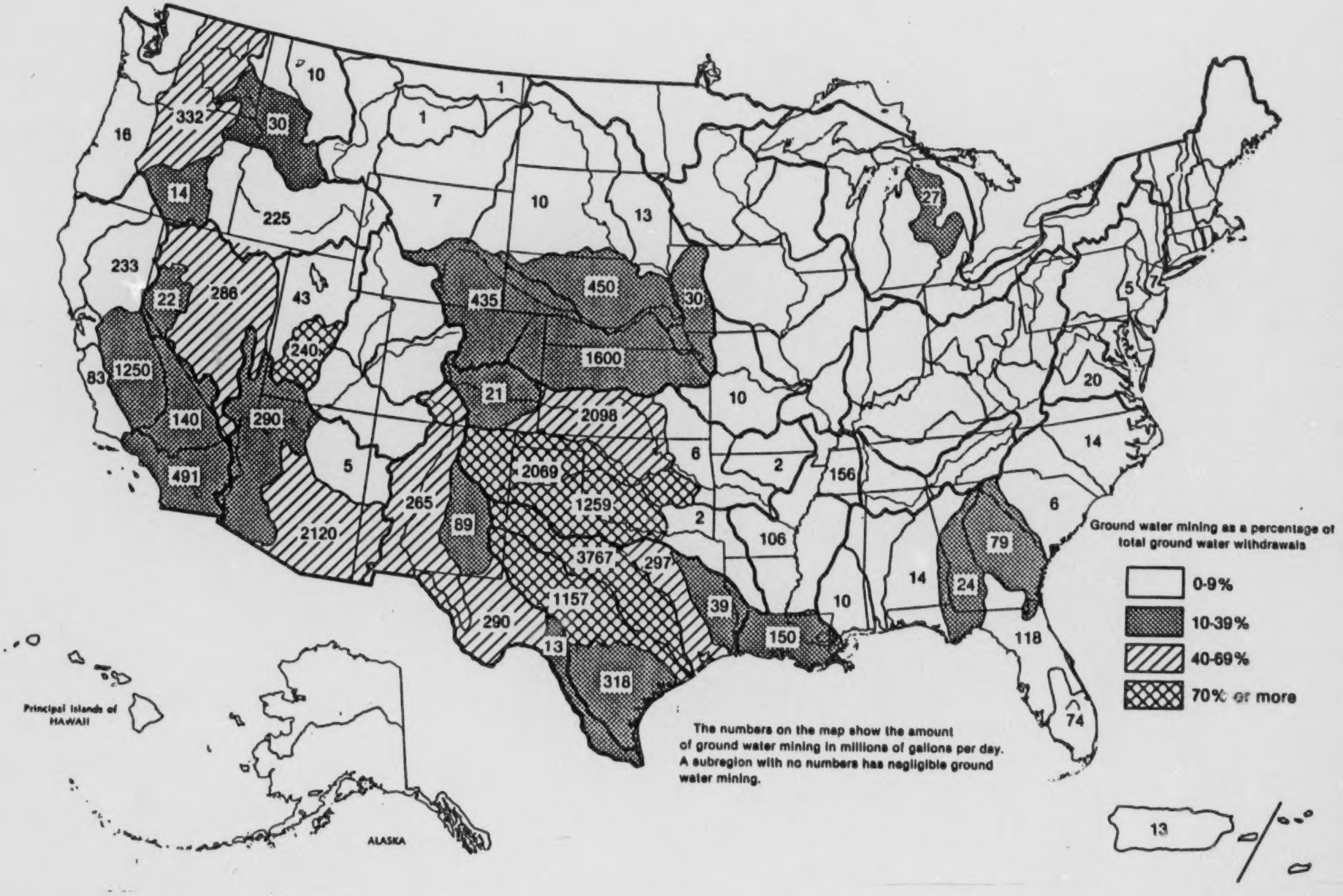

10
332
30
16
1
1
14
7
10
13
225
27
233
22
286
43
435
450
30
5
7
240
1250
83
1600
21
20
140
290
10
2098
14
491
5
2069
6
2
156
265
89
1259
2
6
106
2120
3767
297
79
39
14
24
1157
290
10
150
118
13
318
74
13
Principal Islands of HAWAII
ALASKA
Ground water mining as a percentage of total ground water withdrawals
0-9%
10-39%
40-69%
70% or more
The numbers on the map show the amount of ground water mining in millions of gallons per day. A subregion with no numbers has negligible ground water mining.

Figure 48. Areas of groundwater mining, 1975 (383).

Table 16. Fresh Water Withdrawal and Consumption by Various Uses by Water Resource Region, 1975 With Projects to 2030[1]

Water resource region		Year			
		1975	1985	2000	2030
Missouri	Total withdrawal, mgd^{-1} [2]	38,016	48,037	44,359	44,034
	Total consumption, mgd^{-1}	15,469	19,206	19,913	22,450
	Irrigation, %	91.9	91.6	88.4	85.0
	Steam electric cooling, %	0.4	1.2	3.2	5.8
	Manufacturing, %	0.9	0.6	1.0	1.5
	Domestic and commercial, %	2.1	1.9	1.9	2.1
	Other, %[3]	4.7	4.7	5.5	5.6
Arkansas-White-Red	Total withdrawal, mgd^{-1}	12,868	13,799	13,337	13,656
	Total consumption, mgd^{-1}	8,064	8,769	8,887	10,518
	Irrigation, %	87.4	85.2	80.2	73.4
	Steam electric cooling, %	1.1	2.7	5.1	8.8
	Manufacturing, %	2.0	2.6	4.1	5.8
	Domestic and commercial, %	4.3	4.3	4.6	4.9
	Other, %[3]	5.2	5.2	6.0	7.1
Texas Gulf	Total withdrawal, mgd^{-1}	16,925	15,932	14,991	16,893
	Total consumption, mgd^{-1}	11,259	10,227	10,529	13,971
	Irrigation, %	83.0	74.3	57.9	47.3
	Steam electric cooling, %	0.9	2.6	9.4	14.4
	Manufacturing, %	t	0.1	0.2	0.3
	Domestic and commercial, %	4.6	5.6	6.2	6.0
	Other, %[3]	11.5	17.4	26.3	32.0

---

[1] Data from USDA Forest Service (1980, 226).

[2] Million gallons per day.

[3] Includes mineral extraction.

Table 17. Grazing Available by Ecosystem and Management Level, 1976[1]
(Thousand animal unit months)

Ecosystem	Total	Management level Some livestock	Extensive management	Intensive management	Livestock maximized	Exploitation grazing
Plains grassland	54,325	3,110	24,852	9,854	7,331	9,178
Prairie	45,350	925	15,104	7,523	15,558	6,241
Shinnery	1,848	117	536	643	511	42
Texas savanna	16,493	434	1,337	6,830	1,094	6,799

[1] USDA Forest Service (1980, 226).

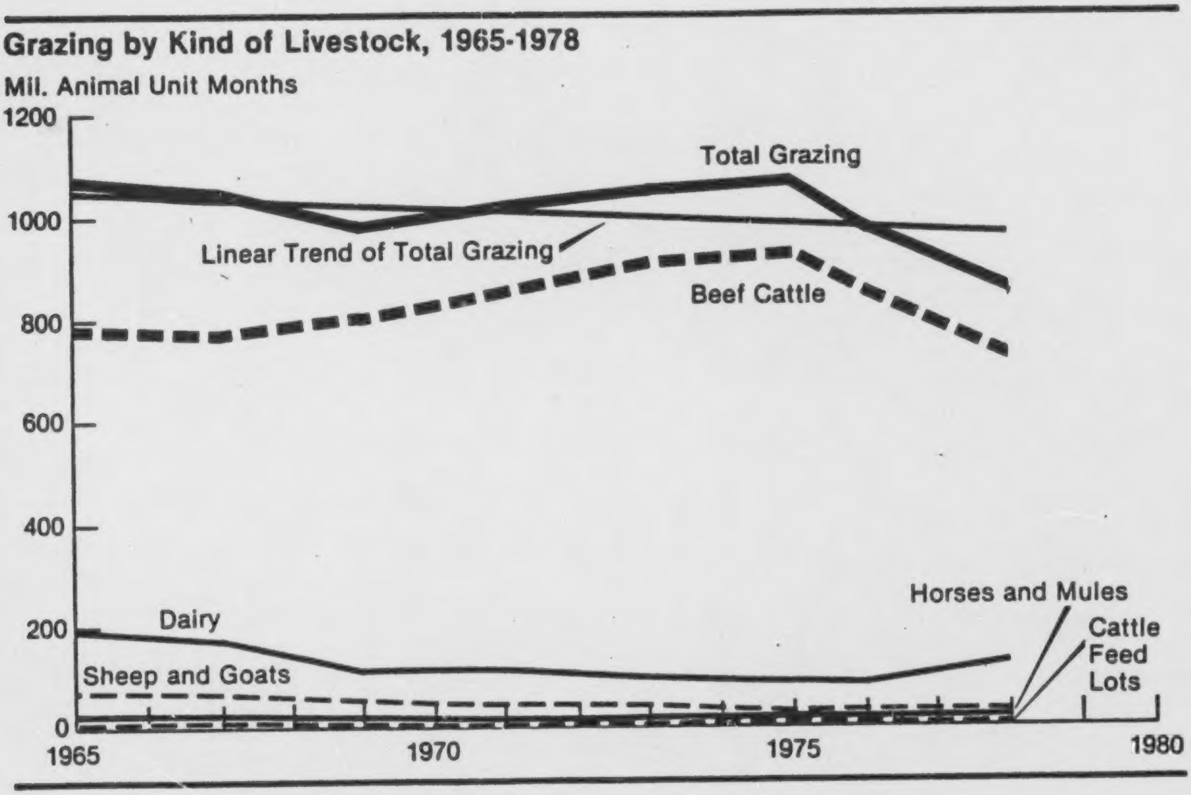


Figure 49. Grazing by kind of livestock, 1965-1978 (226).

Best management for maximum, sustained net ranch income usually results in high range condition and proper use and thus provides for many other uses automatically.

4.4.5 Use of Range Vegetation for Fuel Production

Rangelands do not have the potential for producing alcohol fuels that croplands have. Nor do they have the potential for combustible fuels that forests have. However, these products displace other crops or forest. Rangelands of the Great Plains are occupied by vast quantities of brush that reduce range condition and the productivity and quality of the rangelands for a wide range of uses. Vast sums are spent annually on brush control. Standing crops of brush are especially great in the Texas savanna and in the thickets of brush and low trees in the oak savanna. Large quantities are also found in Shinnery and deteriorated ranges dominated by mesquite and sagebrush. These great quantities of woody biomass are promising for production of methanol and hydrocarbon by gasification plus catalytic synthesis (300) or by anaerobic digestion. Brush biomass seems to offer more promise for fuel than hydrocarbons produced by plants cultivated in the desert (301).

Among the problems involved in developing this resource are the large areas with relatively low weight per area and the effect of the large machinery required on the hydrologic cycle because of compaction.

4.4.6 Recreation

The potential for development of recreation as a business is especially great for developed recreation in scenic areas near population centers, especially where large water impoundments are available. The Forest Service anticipated increases of 39% in land-based recreational activities, 58% increase in water-based activities and a 100% increase in snow and ice-based recreational activities between 1977 and 2030 in the Great Plains region (226). These trends offer income potential for private business.

The potential for increased game populations is large, but has been developed only in the Texas savanna, largely on the Edwards Plateau. In this area income from game approaches that from livestock, especially during dry years and may exceed that from livestock during drought cycles (390). There has also been considerable development of game ranches featuring both exotic and native wildlife (392, 393). In other areas there has been only limited development of fee hunting (391, 405), guest lodges and guide service, although there are several ranches that produce bison for meat and for trophy hunting.

Most of the literature on livestock-wildlife relationships emphasize conflicts, while relatively few are concerned with more efficient use of the range by a combination of grazing including game animals (21). Two important barriers preventing the development of livestock-wildlife operations have been the lack of a way to efficiently market game values and the lack of a suitable methodology for determining optimum proportions. The latter problem is being solved through various optimization procedures (see section 5.3.5). The first problem will require joint action with state game departments and is far from solution. In the Great Plains, the best way to have an abundance of game (big game, upland game, migratory waterfowl, small game, etc.) is to make it profitable for the individual land owner to manage for game abundance.

Interest in non-consumptive recreational experiences is increasing -- hiking, backpacking, camping, photography, etc. In the Great Plains this need is served through local and state parks, state wildlife production areas and public shooting areas, the National Park System (Fig. 50, 382), National Wildlife Refuges (Fig. 51, 382) and over 3 million acres in the National Grasslands managed by the U. S. Forest Service (395). There has also been demand for wilderness which has been met on the federal lands. The Wilderness Preservation System was quite sparse in 1975 (Fig. 52, 382) with several additional areas under study (Fig. 53, 382). In 1980, the Forest Service reported a total of nearly 150,000 a of wilderness in the Great Plains (Table 18, 226) with nearly a 70% increase endorsed by the administration. While most wilderness is on federal land, some does occur on land owned privately or by state and local governments as indicated by a complete list compiled in 1975 (394). However, in general, private landowners have not been able to capitalize on the demand for non-consumptive recreation.

4.4.7 Research and Education

Relatively large range experiment stations on the Great Plains are operated by the Science and Education Administration of the U.S.D.A. near Miles City, Montana; Mandan, North Dakota; Nunn, Colorado; and Ardmore, Oklahoma. State Agricultural Experiment Stations have experimental ranges near Bismarck, North Dakota; Buffalo, South Dakota; Philip, South Dakota; Scottsbluff, Nebraska; Akron, Colorado; Manhattan, Kansas; El Reno, Oklahoma; and near Throckmorton, Sonora, Barnhart, and Uvalde, Texas; and Ft. Stanton, New Mexico. In addition research organizations have a large number of smaller areas used for research. Many private ranches are used for educational tours and for cooperative research.

The area of relatively undisturbed lands in the range country is relatively small. Natural areas are important for developing criteria for the determination of range sites, range condition classes and trend in range

NATIONAL PARK SYSTEM (382)

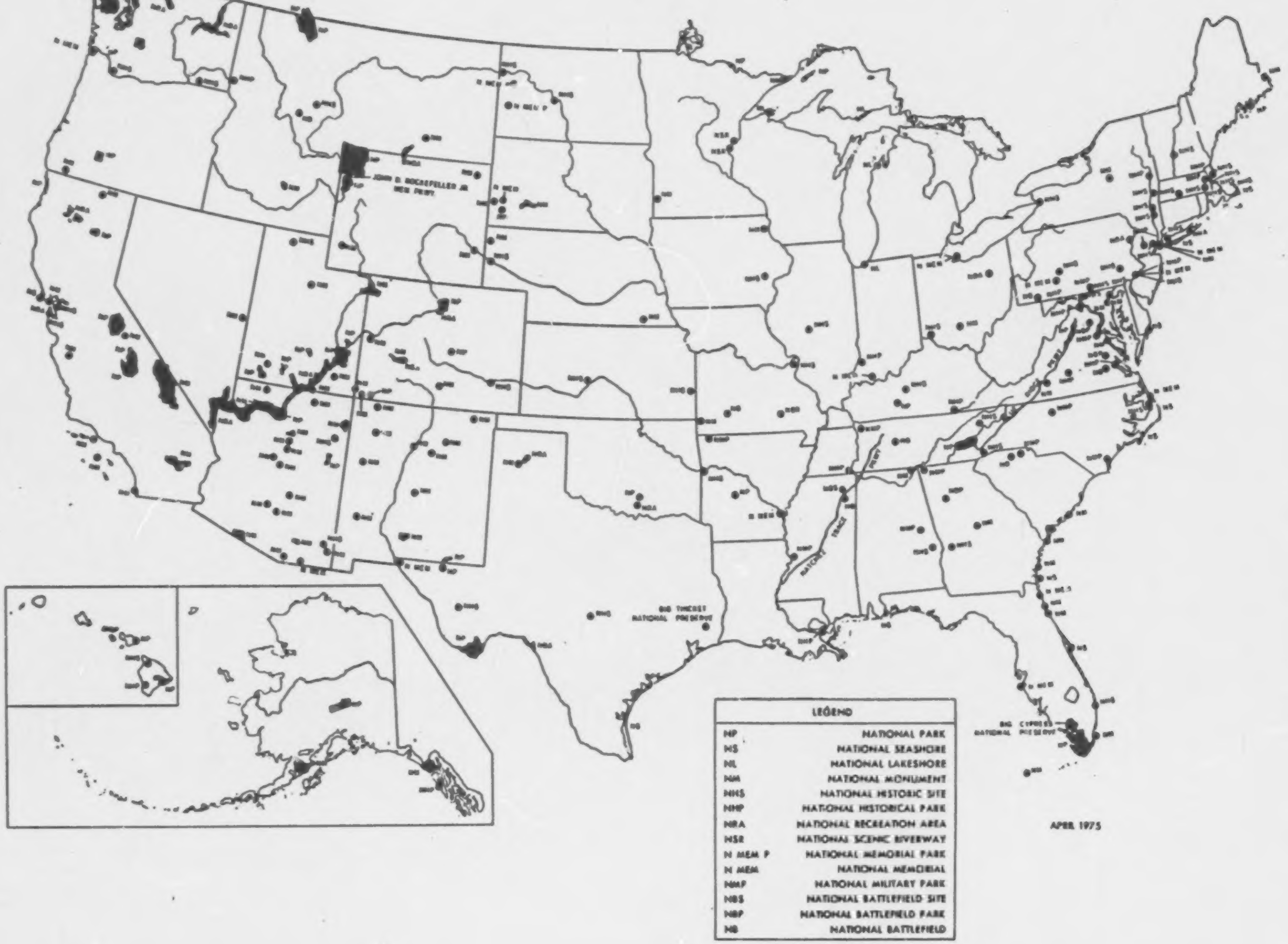

JOHN D. ROCKEFELLER JR MEM PKWY
BIG THICKET NATIONAL PRESERVE
NATCHEZ TRACE
BIG CYPRESS NATIONAL PRESERVE
LEGEND
NP NATIONAL PARK
NS NATIONAL SEASHORE
NL NATIONAL LAKESHORE
NM NATIONAL MONUMENT
NHS NATIONAL HISTORIC SITE
NHP NATIONAL HISTORICAL PARK
NRA NATIONAL RECREATION AREA
NSR NATIONAL SCENIC RIVERWAY
N MEM P NATIONAL MEMORIAL PARK
N MEM NATIONAL MEMORIAL
NMP NATIONAL MILITARY PARK
NBS NATIONAL BATTLEFIELD SITE
NBP NATIONAL BATTLEFIELD PARK
NB NATIONAL BATTLEFIELD
APRIL 1975

Figure 50. National Park System (382).

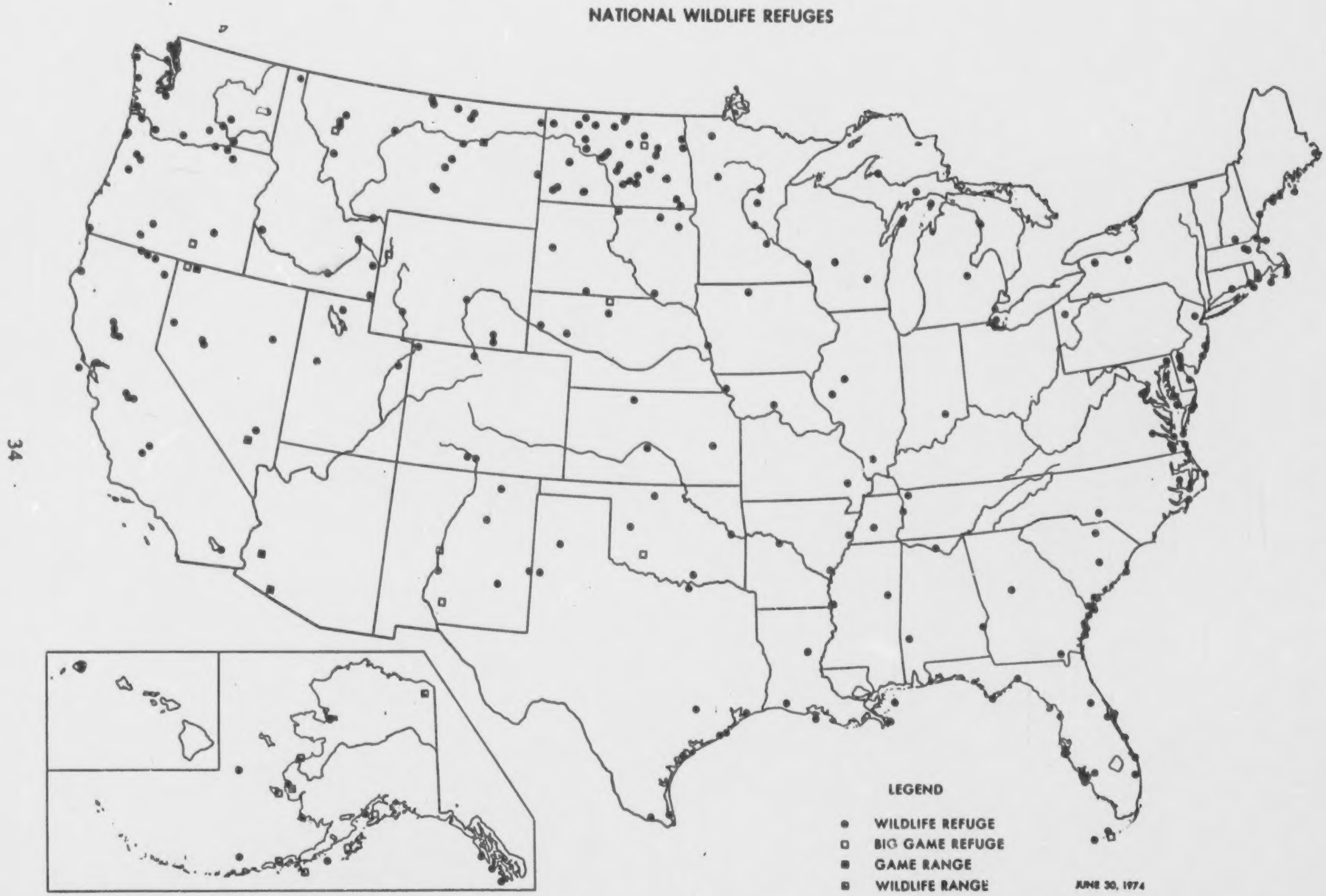

NATIONAL WILDLIFE REFUGES
LEGEND
● WILDLIFE REFUGE
□ BIG GAME REFUGE
■ GAME RANGE
▣ WILDLIFE RANGE
JUNE 30, 1974
34

Figure 51. National Wildlife Refuges (382).

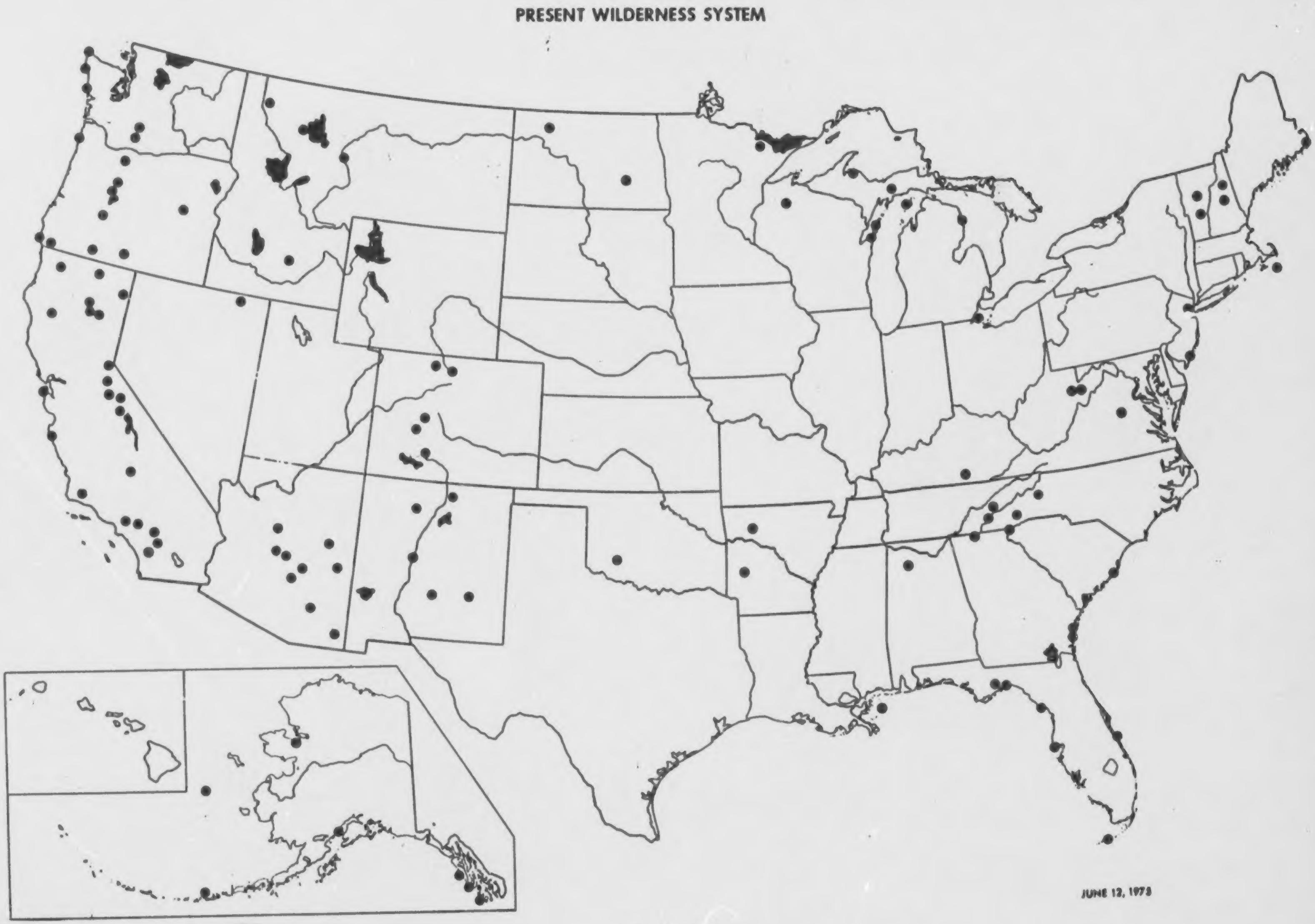

PRESENT WILDERNESS SYSTEM
JUNE 12, 1973

Figure 52. Present Wilderness System (382).

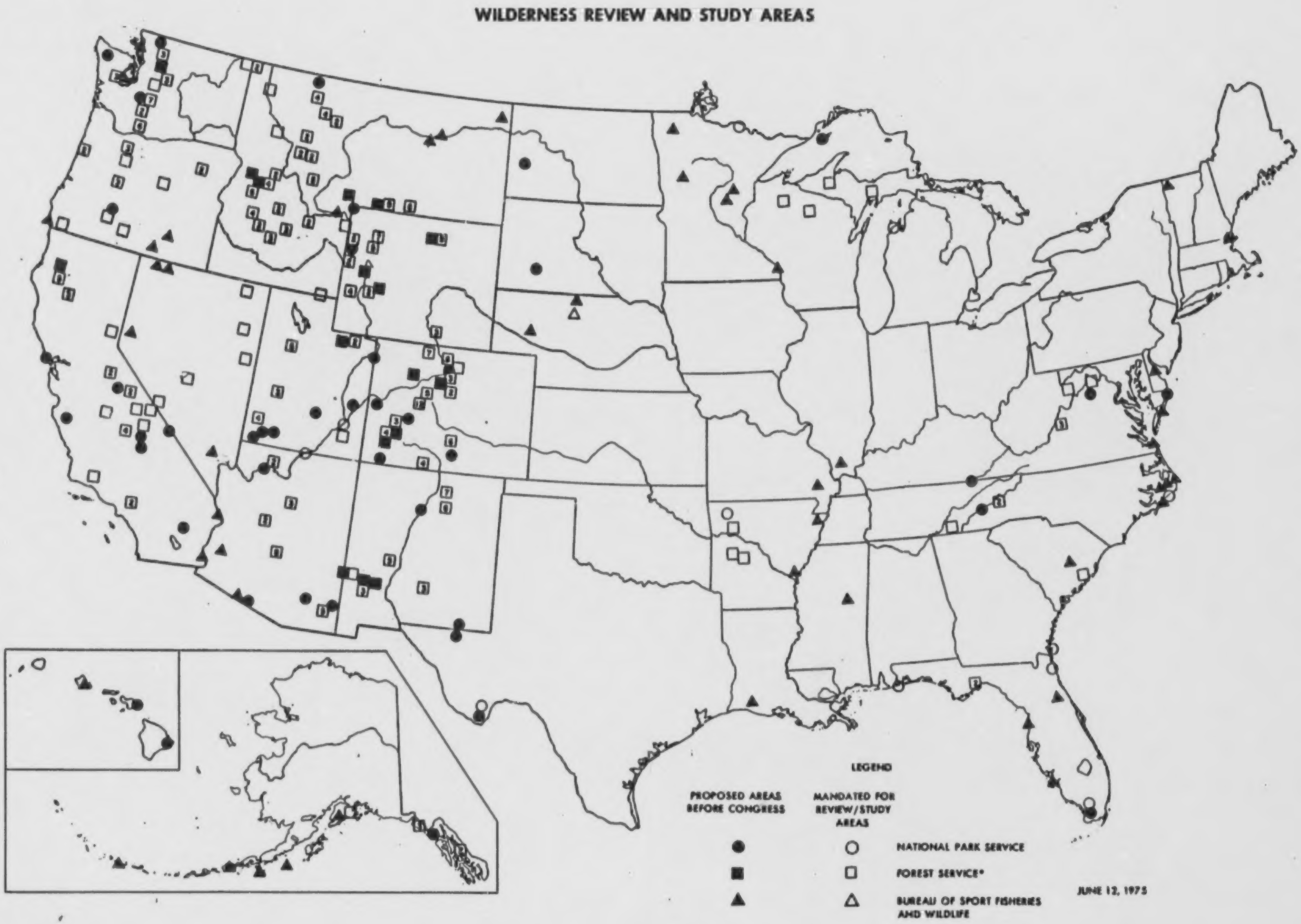

WILDERNESS REVIEW AND STUDY AREAS
LEGEND
PROPOSED AREAS BEFORE CONGRESS
MANDATED FOR REVIEW/STUDY AREAS
● ○ NATIONAL PARK SERVICE
■ ☐ FOREST SERVICE*
▲ △ BUREAU OF SPORT FISHERIES AND WILDLIFE
JUNE 12, 1975

Figure 53. Wilderness review and study areas (382).

Table 18. The National Wilderness Preservation System in the Great Plains[1]

	Existing units	Units endorsed by the administration
Plains grasslands	132,419	189,580
Prairie	12,315	49,219

[1] USDA Forest Service (1980, 226).

condition. They are needed as outdoor laboratories for the study of ecosystems, how they operate and how to manipulate them. They are important to preserve the diverse gene pools of native species of plants and animals which may be useful later for genetic improvement of domesticated species or for new domestication. A review of the natural area or reference area concept (396) has been prepared by the Society for Range Management which is in the process of collating these areas for various states.

The Nature Conservancy is a private organization, supported by donations, devoted to the preservation of areas of natural ecosystems that are in danger of being destroyed. By the end of 1977 this organization owned just under 40,000 a of grassland in tracts ranging from 5 to over 8,000 a in 12 midwestern states (Fig. 54, 397).

All of these lands, both public and private, are valuable teaching laboratories. It is impossible to do a thorough job of teaching people to manage the resources of range ecosystems without getting on the land in order to see, to manipulate, to measure and to understand the nature of the ecosystem.

Research and educational activities have great significance for the wise management of our rangelands, for the economics of ranching, and for the education of professional range scientists, and the general public. Furthermore, the understanding of the operation of natural ecosystems provides better insights into the management of man-dominated ecosystems, such as our croplands and cities.

4.5 Compatibility of Uses

Obviously some uses of rangelands are incompatible with other uses. However, most cases of supposed incompatibility are due to failure of different ward march considered it a wasteland. They soon discovered, however, that it was much easier to turn the prairie sod to provide a seed bed for their crops than to saw and chop trees from the forests. After the Civil War, the rush for land made available by the 1862 Homestead Act, the perfection of the moldboard plow, the relegation of most Indian tribes to reservations, and the use of barbed wire fences altered the prairie. When the prairie became crisscrossed with fences, the free movement of cattle was restricted. Invariably, cattle were kept in enclosures in greater numbers than the range could adequately support. They could not move on when the grasses were depleted. The grasses and forbs had no chance to manufacture reserve foods for storage in the roots. This gradual weakening of the existing grasses and other plants utilized by the cattle caused an imbalance in the dominant life forms. Weedy annuals and less palatable grasses replaced the native grasses. In addition, the prevention of prairie fires allowed shrubs and trees to invade the essentially treeless grassland.

Has the prairie been permanently altered? In a way, yes.

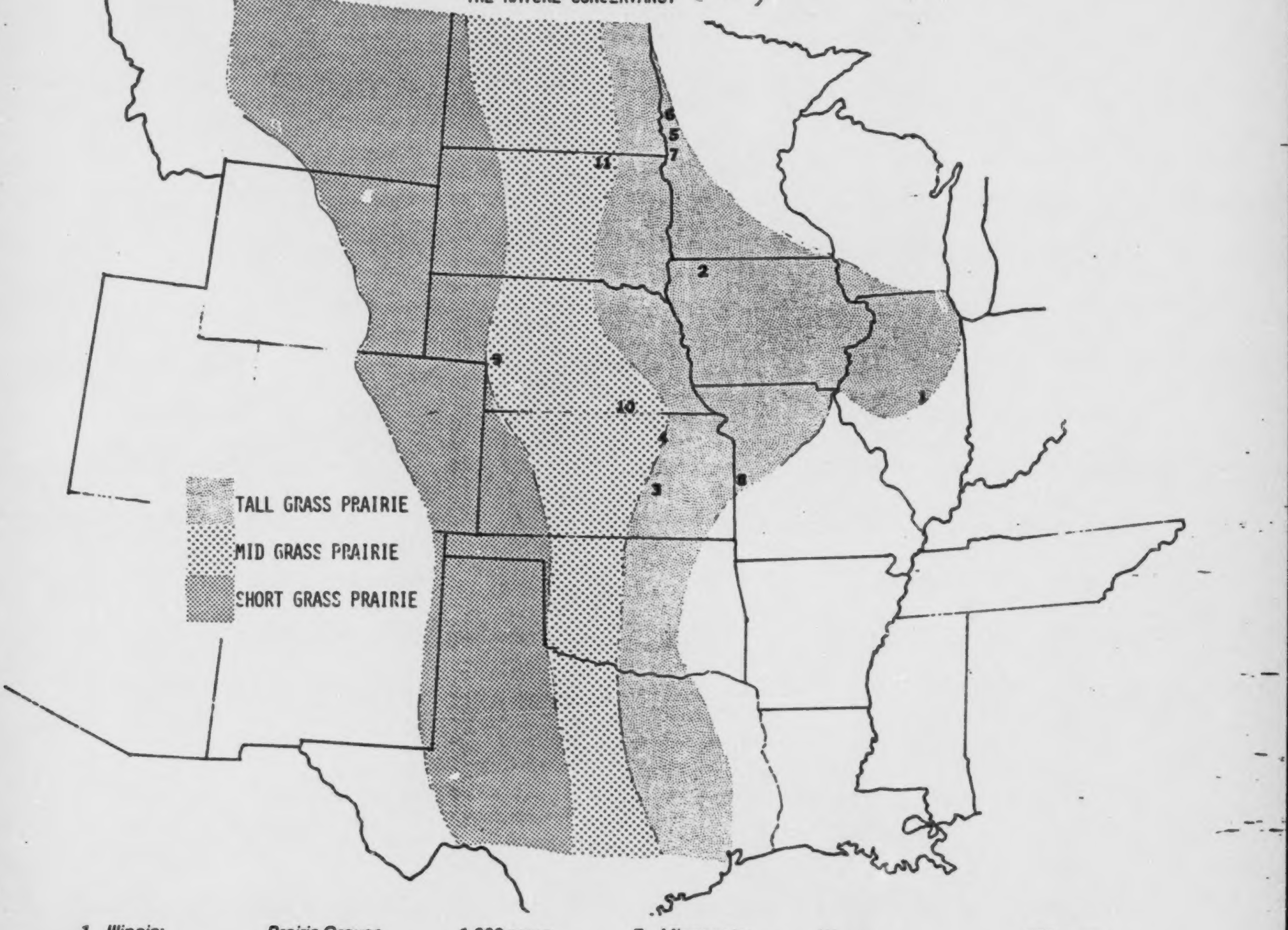
Preserving Prairie

All of us, in one way or another, practice preservation. The Dead Sea Scrolls, the Declaration of Independence, grandfather's spade or butter churn—all have some significance in terms of preservation. The prairie is part of our heritage. Many of our ancestors lived their entire lives on the ragged edge of civilization in "soddies," primitive places of protection where masses of prairie turf literally formed the walls and ceilings of their homes.

The Great Plains prairie has a permanent place in the cultural life of the heartland of North America. The prairie belongs to all of us. It is a natural environment that young children should see and enjoy. Students of science and history should study it. Artists and farmers should be awed by its aesthetic beauty as well as its utility.

As a scientist, I marvel at the sight of a bobolink or red-winged black-bird swaying in he wind on a native compass plant in the prairie. The pasque flower in spring, the red-orange of prickly pears flowering in summer, and the many white and blue asters

FIGURE 1. PRINCIPAL PRAIRIE AREAS OF THE NATURE CONSERVANCY (397)



1.	*Illinois:*	*Prairie Grouse*	*1,600 acres*
2.	*Iowa:*	*Freda Hafner*	*110 acres*
3.	*Kansas:*	*Flint Hills*	*2,188 acres*
4.	*Kansas:*	*Konza*	*8,036 acres*
5.	*Minnesota:*	*Bluestem*	*1,200 acres*
6.	*Minnesota:*	*Pembine Trail*	*1,600 acres*
7.	*Minnesota:*	*Western*	*600 acres*
8.	*Missouri:*	*Osage*	*1,195 acres*
9.	*Nebraska:*	*Arapaho*	*1,280 acres*
10.	*Nebraska:*	*Willa Cather*	*610 acres*
11.	*South Dakota:*	*Samuel H. Ordway*	*7,600 acres*

Figure 54. Principal prairie areas of the Nature Conservancy (397).

users to sincerely desire to be compatible. The best way to harmonize competing uses in the Great Plains region, where some 95% of the land is in private ownership, is to find a way for different uses to be integrated into the ranch operation as increased net ranch income.

Compatibility of some of the major uses of Great Plains rangelands are scored from 1 to 5 in a matrix (Table 19). This matrix indicates higher compatibility among uses than evaluations made by some. These are estimates of the authors based on literature review and experience, attempting to ignore conflicts that are based on biases of the users, rather than on facts.

5. RANGELAND DETERIORATION AND IMPROVEMENT

5.1 Rangeland Deterioration

5.1.1 Agents of Deterioration

Rangeland deterioration may be the result of prolonged drought (section 2), frequent traffic with off-road vehicles, frequent mowing, overgrazing by livestock or wildlife and other factors. Overgrazing by prairie dogs deserves special comment. This has been a serious concern in the northern Great Plains especially in western South Dakota. Prairie dog populations were kept low through an extensive poisoning program for several decades up until 1971. Data on prairie dog colonies in Conata Basin near Badlands National Monument on the Buffalo Gap National Grasslands were not available for 1971, the year in which poisoning was stopped. However, from 1968-1976, the number of acres occupied by prairie dog colonies increased 1017% and from 1975-1976 increased 34% (417). Comparable figures in Badlands National Monument, ungrazed by livestock, were 68% and 2%, respectively. One 400 square mile area had 17% of the

Table 19. Compatibility of Important Uses at the Same Place or in the Same Vicinity in the Great Plains[1/]

	Surface mining (reclaimed)	Subsurface mining	Ground water development	Hydrothermal power	Solar power development	Wind power development	Transportation corridor development	Biomass for fuels	Livestock management	Big game management	Small game and fur bearer management	Upland game bird management	Migratory waterfowl management	Non-game biota	Endangered, threatened and sensitive species management	Large water impoundments	Small water impoundments	Wilderness	Developed recreation	Consumptive recreation	Non-consumptive recreation	Scientific and educational activities	Human habitat
Surface mining (reclaimed)	-	1	1	1	1	1	1	4	2	3	3	3	-	3	3	1	1	3	1	3	3	4	3
Subsurface mining		-	5	5	1	1	1	1	2	2	2	2	2	2	2	5	5	2	2	2	2	2	2
Ground water development			-	5	1	1	1	1	1	1	1	1	1	1	1	5	5	2	1	1	1	1	1
Hydrothermal power				-	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Solar power development					-	1	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Wind power development						-	5	1	1	1	1	1	1	1	1	5	5	5	1	1	1	1	1
Transportation corridor development							-	4	4	4	4	4	1	4	4	5	5	5	4	4	4	4	4
Biomass for fuels								-	4	4	4	4	4	4	4	5	5	5	4	4	4	4	4
Livestock management									-	2	1	2	2	1	4	5	1	1	5	2	2	2	2
Big game management										-	1	1	1	1	4	5	1	1	5	1	1	1	2
Small game and fur bearer management											-	1	1	1	4	4	1	1	5	1	1	1	2
Upland game bird management												-	1	1	1	5	1	1	5	1	1	1	2
Migratory waterfowl management													-	1	1	1	1	1	5	1	1	1	2
Non-game biota														-	1	5	1	1	5	1	1	1	2
Endangered, threatened and sensitive species management															-	5	1	1	5	1	1	1	5
Large water impoundments																-	5	5	1	1/5	5	5	5
Small water impoundments																	-	2	1	1	1	1	5
Wilderness																		-	5	1	1	1	5
Developed recreation																			-	5	5	5	2
Consumptive recreation																				-	3	1	1
Non-consumptive recreation																					-	1	1
Scientific and educational activities																						-	5
Human habitat																							-

[1/] Personal evaluation of the authors based on literature evaluation and experience in the Great Plains.
Compatibility is scored as follows:
1 Minor conflict or none, compatible
2 Some conflict, largely compatible
3 Moderate conflict, moderately compatible
4 Extensive conflict, slightly compatible
5 Complete conflict, incompatible

area occupied by prairie dog colonies. The problem was severe over much of the Pine Ridge Indian Reservation, as well as over large acreages of the Buffalo Gap National Grasslands. Control is more difficult because prairie dog towns in the region are the home of an endangered species, the black-footed ferret. However, a control program has been initiated using zinc phosphide. About 95% control is being obtained in the treated areas. If the presence of the ferret is suspected, towns are not poisoned. Remnant colonies of prairie dogs are allowed to remain.

The prairie dog is a herbivore with dietary preferences similar to but not identical to cattle. In addition to forage consumption, the prairie dog cuts vegetation to improve visibility. They are also tillers of the soil with extensive underground tunnels and chambers and with bare areas around their burrows. The net effect of prairie dogs is dependent on density. As with any herbivore, when density is too high, the vegetation is overutilized and range condition deteriorates. Various kinds of tillage, coupled with good grazing management, are proven range management practices. Indeed, U. S. Forest Service researchers have found that areas with prairie dogs (density, herbage utilization, and extent of tillage were not given in preliminary reports) produce more above-ground vegetation than those without (418). Ranchers, confronted with vast acreages of denuded prairie dog towns, remain unconvinced of any beneficial effect. Mechanics of population regulation in the days of the bison are poorly understood, although extensive towns were reported by early explorers [several reports are reviewed by Koford, (52), Smith (428), and King (429)]. In Texas near the turn of the century, Merriam (419) estimated that one colony covered more than 25,000 square miles with about 400 million prairie dogs.

At the present time with low effective predator population, density may be controlled mainly by disease. It seems probable that low densities of prairie dogs with towns occupied for relatively short periods of time would be beneficial in terms of above-ground herbage production. Stimulation of herbage growth would probably exceed consumption. Furthermore, such low-density prairie dog populations probably could be developed as a source of income through sale of meat. However, a careful control program would be required and techniques of management and marketing would have to be developed. The costs of such a venture may very well exceed the returns for the rancher.

Without question, prairie dogs have been and continue to be an important source of range deterioration on the Great Plains. They must be controlled and managed, just as any other herbivore. Most often, however, range deterioration on the Great Plains has been the result of prolonged heavy grazing by domestic livestock.

5.1.2 The Interacting Causes

5.1.2.1 Stressors

The climate of the Great Plains is severe with extreme variation from day to day, month to month and year to year. Both wet years and extensive droughts are common (section 2). This environment puts great stress on the Great Plains rancher. Yet, as ranchers of other less variable regions, he must also deal with variable and often unfavorable product prices, variable and often unfavorable costs of production, high and persistent inflation, high and variable interest rates and often, inappropriate governmental action.

5.1.2.2 Basic Requirements

Some basic requirements of management to minimize the effect of the "stressors" listed in the previous paragraph are high efficiency, reserves, flexibility, and mobility. Efficiency can be measured in terms of low costs of production or high returns per unit of investment. New technology (such as bigger tractors, better machinery, and more intensive practices) may not result in greater efficiency, especially with increasingly high costs of fuel, fertilizer, and machinery relative to livestock prices.

Reserves of old grass, hay, silage or stored grain are essential for minimizing the effect of fire, hail, snow, blizzard or short-term drought. However, high interest rates make provision for such reserves very costly, especially if kept for very long. Reserves in the form of investments in inflation-hedging securities and in the form of good credit are immensely valuable. Inflation and high interest rates make such reserves much more difficult to maintain.

Since it is difficult to carry harvested feed over from long wet periods to the long dry periods characteristic of the climate of the Great Plains, flexibility in management is required. Flexible ranch management begins with a flexible livestock operation. The Plains rancher must always be able either to 1) adjust numbers of animals to a fluctuating forage supply or 2) to supply feed from other sources. The second alternative is feasible only for relatively short periods. Cow-calf operations are quite inflexible. In order to reduce numbers, part of the costly breeding herd must be sold, usually when prices are low because of increased numbers of cows going to market. Cow-yearling operations, where calves are kept over winter at low rates of gain for optimum performance on summer range and sold as yearlings, are less efficient, but much more flexible, in that numbers can be adjusted by the sale of calves or yearlings, which are much more marketable products. Sheep operations are more flexible than cattle. Operations with more than one enterprise are more flexible than those with only one source of income. Ranchers with flexibility in season of use, grazing system and stocking rate are better buffered against the hazards of drought than those with less flexible grazing operations.

Ranches which have opportunity to move cattle out of the drought area to other owned lands or to leased lands, or ranches which have sources of cheap feed which can be imported are better equipped to minimize drought effects than those which are less mobile. However, increasing transportation and interest costs are reducing this advantage.

5.1.2.3 Factors Predisposing to Range Deterioration (430)

5.1.2.3.1 Economic factors. Small ranch size and/or low net ranch income reduce the flexibility of the manager in dealing with uncertainty. This is especially true with high fixed costs which are a common feature of ranches, especially small ones. High land costs, property taxes, machinery repairs and depreciation all limit flexibility. Inflexible mortgage repayment schedules impose a great burden on Great Plains ranches with extremely variable forage production. Both inflation and high interest rates predispose to management for the present rather than making provision for an uncertain future. These factors as well as others, such as uncertainty of tenure on leased land, all predispose toward overuse and range deterioration.

5.1.2.3.2 Speculative opportunity. If sale values of land do not reflect differences in range condition, especially when land values are inflating, speculators are tempted to deteriorate the range by grazing exploitatively and then selling the land to an unsuspecting buyer at a higher price. While this practice has not been uncommon, it is probably not a major cause of range deterioration.

5.1.2.3.3 Judgment factors. These are some of the more common factors predisposing toward range deterioration. Among some of the frequently observed judgments that predispose toward deterioration are the following:

1) Delaying stocking rate adjustments during drought because of the expectation of rain;

2) Overusing limited seasonal range in order to obtain full use of forage or feed;

3) Deciding that the cost of breeding herd reduction or liquidation during drought is greater than the cost of range deterioration, or of other alternative strategies;

4) Choosing an inflexible livestock operation in order to maximize efficiency;

5) Deciding that the cost of early marketing during drought is greater than the cost of range deterioration;

6) Putting blind trust in the wisdom of using intensive agronomic practices on rangeland without adequate testing and analysis;

7) Using residue from proper use (or overuse) in a drier area as a criterion of proper use in a wetter area;

8) Uncritically following traditional patterns of management;

9) Believing that it is more economical to sequentially deteriorate and rebuild a range than to maintain it at high condition.

The doubtful wisdom of such judgments should be tested in the crucible of research and further education, resulting in a better understanding of range ecosystems and of the economics of the ranch business.

5.1.3 Patterns of Deterioration

Although there are important exceptions, generally, smaller ranches are in lower range condition than large ones. Ranches with large supplies of harvested feed are in lower range condition than those with less (297). Ranges deteriorate during drought, often because stocking rates appropriate for wet years are maintained during dry years. Often more damage is done by overuse druing the first spring with good soil water than was done during drought, because of lowered food reserves in valuable perennial range plants. Ranges deteriorate more during periods with inflation and during periods with high interest rates. Range condition is lower in the southern than in the northern Plains.

5.1.4 Extent of Deterioration

Rangelands of the Great Plains improved in range condition from 1963 to 1977, according to estimates made by the Soil Conservation Servies (Table 10).

5.1.5 Results of Rangeland Deterioration

The effect of poorly-managed and well-managed grazing by different groups of grazers on selected ecosystem properties is summarized in Table 20, with references to the literature. In general, poorly-managed grazing with overuse reduces productivity and quality of Great Plains rangelands whether done by livestock, game or burrowing rodents, while well-managed grazers improve or maintain high quality and productivity.

The deterioration of rangelands due to overgrazing follows a similar pattern, regardless of the kind of herbivore or the continent on which the grazing occurs (2). The range is a great cafeteria from which grazing animals select those plant species, ecotypes, biotypes and plant parts in the general

Table 20. Effects of Grazing[1/] During the Growing Season by Different Groups of Species at Different Managment Levels on Selected Properties of Range Ecosystems of the Great Plains

Effect on selected ecosystem properties	Species of grazer and level of management					
	Livestock		Game		Burrowing rodents	
	Poorly managed, over use	Well-managed, proper use	Poorly-managed, over use	Well-managed, proper use	High population density	Low population density
Vegetation (1, 2, 3, 4, 8, 9, 10, 11, 16, 33, 51, 52, 53, 54, 55, 56, 66, 67, 68, 69, 70, 216, 217, 218, 219)						
Stratification	4	6	4	6	4	6
Periodicity	4	6	4	6	3	5
Diversity	4	6	4	6	3	5
Botanical composition (of both species and biotypes)						
Escape grazing	6	4	6	4	6	4
Grazing resistant	6	4	6	4	6	4
Drought resistant	6	4	6	4	6	4
Peak above-ground standing crop	4	6	4	6	4	6
Net primary production						
Total	2	2	2	2	2	2
Above:Below-ground ratio	4	6	4	6	4	6
Mulch	4	6	4	6	4	6
Forage utilization	6	2	6	1	6	3
Range condition	4	6	4	6	4	6
Managed grazing animals (1, 2, 3, 7, 8, 9, 10, 11, 30, 35, 66, 67, 69, 70, 72)						
Forage intake	4	6	3	5	4	6
Nutritional concentration of diet	4	6	3	5	4	6
Growth	4	6	3	5	4	6
Reproduction	4	6	3	5	4	6
Mortality (unless fed)	4	6	3	5	4	6

Table 20. Continued

Effect on selected ecosystem properties	Species of grazer and level of management					
	Livestock		Game		Burrowing rodents	
	Poorly-managed, over use	Well-managed, proper use	Poorly-managed, over use	Well-managed, proper use	High population density	Low population density
Microclimate(202, 214)						
Solar radiation	5, 6	3, 4	5, 6	3, 4	5, 6	3, 4
Maximum soil temperature	5	3	5	3	6	3
Minimum soil temperature	3	5	5	3	4	5
Wind movement	6	4	6	4	6	4
Canopy vapor pressure deficit	4, 2	6, 2	4, 2	4, 2	4, 2	6, 2
Evaporation						
Hydrologic cycle(12, 15, 204, 207, 210, 211, 212)						
Interception	2	2	2	2	4	6
Intake	4	6	4	6	3	3
Percolation	3	5	3	5	3	3
Runoff	5	3	5	3	5	5
Soil Water	5, 2	3, 2	5, 2	3, 2	5	3
Precipitation amount	1	1	1	1	1	1
Nitrogen cycle (129, 220, 221, 222, 223)						
Fixation	3	5	3	5	3	5
Vaporization	6	3	1	1	1	1
Export	3	5	1	1	1	1
Release from organic matter	5	3	5	3	5	3
Soil erosion(201, 203, 205, 206, 208, 209, 213)						
Water	5, 6	3, 4	5, 6	3, 4	6	3
Wind	5, 6	3, 4	5, 6	3, 4	6	3

Table 20. Continued

Effect on selected ecosystem properties	Species of grazer and level of management					
	Livestock		Game		Burrowing rodents	
	Poorly-managed, over use	Well-managed, proper use	Poorly-managed, over use	Well-managed, proper use	High population density	Low population density
Net ranch income (65)	4	6	4	6	4	6

---

[1] Change from intermediate management level or intermediate population level.
1 No effect
2 Effect variable
3 Slight decrease
4 Large decrease
5 Slight increase
6 Large increase
These are estimates of the authors based on literature evaluation and experience for ordinary upland range sites.

order of their palatability to each particular animal species, age class and production-level class at a particular time. Areas closest to ordinary occupation areas, such as areas near water, near bed-grounds, near salting areas, etc. are grazed first and most often. The timing of herbage growth in relation to environment varies with species, ecotype and biotype, resulting in periodicity of the vegetation and a changing order of palatability for grazing animals. Plant growth is also stratified, with plants rooting at different depths and growing to different heights, and patterned in space, thus minimizing competition and increasing the efficiency of production of the plant community.

When regrowth occurs after grazing, regrowth is more palatable than the older growth and is sought and grazed, often repeatedly. When a plant is grazed, if other factors are equal, grazers such as cattle, sheep, horses, bison, etc. remove a greater proportion of the plant which is most accessible. Plants which are very unpalatable, very tall or very short, which have thorns or spines, or which are dormant during the grazing season when others are growing, escape grazing. When plants are grazed, leaf area is reduced, total photosynthesis is decreased, photosynthesis per area of leaf may be increased, transpiration is decreased, ability to remove soil water at high water tension is decreased, root elongation is stopped and regrowth is stimulated 1) if apical dominance is broken when food storage is adequate, environmental conditions (temperature, water, light and fertility elements) are favorable, and enough photosynthetically active tissue remains, and 2) if basal buds are present and adequately developed. If regrowth occurs, herbage will be more palatable with higher nutritional value and food reserves usually will be decreased.

If heavy grazing removes a large proportion of the foliage frequently with short intervals between grazings, especially if the heavy grazing occurs when the morphological and physiological condition of the plant makes it more susceptible to grazing damage than usual, plant vigor and competitive ability are sharply reduced. This is especially true if the environmental conditions are unfavorable and other aggressive plant competitors are present. Reduced competitive capacity is also related to reduced root weight per plant, reduced rhizome and seed production, reduced food reserves, later initiation of spring growth, slower spring growth, slower regrowth after grazing, and often a higher incidence of disease and parasitism.

Some plants are more grazing resistant than others. Grasses with greater leaf replacement potential, greater root:shoot ratios, larger food reserves, stronger stems and leaf bases that break near the point of grazing rather than at or below the ground surface, are more grazing resistant. Grasses with slower growth rate, slower leaf elevation, culmless vegetative shoots or later elevation of the shoot apex, later floral differentiation, lower proportion of reproductive shoots and a larger number of basal and axial buds from which to tiller are more grazing resistant. Likewise, those grasses with rhizomes are more grazing resistant than those without.

When a large proportion of the vegetation is removed by grazing year after year, the standing crop of vegetation and the mulch cover are both reduced. Soils are trampled and puddled when wet. Raindrops strike the bare soil surface, causing rain drop splash and soil sealing. Trampling compacts the soil and reduces macropore space and aeration. Infiltration rate and percolation rate are reduced, while runoff and water erosion and wind erosion are accelerated and may permanently change the nature of the site by topsoil removal, complete profile removal, by channeling and draining a water table, or by deposition of sediment or aeolian material. When the cover of vegetation and mulch is reduced, light intensity, wind movement, maximum temperature and evaporation are increased in the layer near the ground, while minimum temperatures are decreased. In some cases, soil water is increased in deeper layers, because of reduced transpiration, but decreased in the upper layers, while in other cases soil water is reduced throughout the profile, man-made drought occurs, and in severe cases desertification may proceed. Fuel for burning is reduced, incidence and temperature of burning is decreased.

The vegetation is dynamic and generally will come to a steady-state with the degree of grazing disturbance. The vegetation of ranges deteriorated by prolonged heavy grazing will be dominated by those species, ecotypes and biotypes that escape grazing, that are grazing resistant, that are drought resistant, that are not resistant to fire at young stages of growth, and that are characteristic of a drier region. The adaptation to the environment through periodicity and stratification will be disrupted and more of the plant production will be placed below-ground. With different grazing animals, different season of use, different intensities of grazing and other factors, different plant communities with these same general characteristics will be developed.

In Texas savanna, Shinnery and Oak savanna the general effect of overgrazing is thickening of thorny brush and small trees. In the Plains grassland the major effect is the increase of the low-growing shortgrass sod. In the southern part of the Plains grasslands, the dominant effect is the increase of mesquite, short-growing grasses and weedy forbs. In the Prairie the dominant effect is the increase of Kentucky bluegrass and weedy forbs. While these are the major regional patterns, local variations occur due to different range sites or to different patterns of grazing or other disturbance. Range deterioration profoundly disrupts the complex integration of the organisms of the grazing food web as noted in Table 20.

In contrast to these effects, managed grazing is a powerful tool for range improvement as shown in the next section.

5.2 Rangeland Improvement

5.2.1 Goals and Objectives

The specifics of rangeland improvement will be guided by goals and objectives of individual managers. Since 95% of Great Plains rangelands are in private ownership, this means the goals and objectives of private landowners. These range widely, but in general must give great attention to short term economic goals for survival. Long range goals of ranchers generally coincide with the goals of society. However, long range goals, frequently expressed by ranchers, such as to pass their land on to their children in better condition than they received it, are possible only if short term economic goals are fulfilled. Generally, however, short term and long term goals are compatible. It should be a matter of public policy that they be so. In other words, range improvement or the maintenance of high range condition should be economically feasible. The objectives of management should include high range condition as an index of high productivity and quality of rangelands.

5.2.2 Inventory, Assessment, and Problem Definition

These three processes should be involved continually in the management of the private lands. Each rancher should always have an up-to-date inventory of rangeland, cropland, and other land resources, as well as those of livestock and other aspects of the operation. There should be a continual assessment of the resources and the details of operation, a continual refinement of problem definitions and the consideration of alternatives to solve the problems and meet the management objectives.

The federal government through the Renewable Resources Planning Act (RPA) has required the U. S. Forest Service to prepare an up-dated inventory and assessment of the forest and rangelands of the United States and their resources at 5 year intervals (226). The Soil and Water Resources Conservation Act (RCA) requires the Soil Conservation Service to prepare an up-dated inventory and assessment of the status of the soil and water resources on the non-federal lands at 5 year intervals (383). A general summary of the RPA has been prepared (383). More detailed information can be obtained from the data bank maintained under the supervision of the Rocky Moauntain Forest and Range Experiment Station, U. S. Forest Service, U. S. Department of Agriculture, Ft. Collins, Colorado. The nature of the data in the bank is described by the Forest Service (420).

Very rapid advances are being made in the assessment of rangeland resources with multi-spectral scanners (MSS) from aircraft and from satellite and with color infrared aerial photography. Over the period 1972-1980, imagery from Landsats-1,2,3 has been used for many purposes including the refinement of soil delineations, recognition of generalized vegetation types and even the determination of the dry, green standing crop of vegetation (421). The Landsat MSS ground resolution is about 1 acre per pixel with coverage in 4 bands with wave lengths of 0.5 to 0.6 (green), 0.6 to 0.7 (red), 0.7 to 0.8 (near infrared), and 0.8 to 1.1 micrometers (near infrared).

Landsat-D, scheduled for orbiting in late 1981 will be equipped with the same four MSS bands plus a thermal infrared band of 10.5-12.5 micrometers. The satellite will also have a new 6 (or possibly 7) channel thematic mapper which will provide ground resolution less than 1/4 acre except in the thermal infrared band which will have much less resolution. Hopefully, we are approaching the time when relatively precise, timely data on range vegetation can be obtained at 16 day intervals with low cost and rapid turn-around. The potential for range and ranch planning is immense. Furthermore, a spectroradimeter for airborne remote sensing has been designed with 500 channels from 0.4 to 1.1 micrometers which will provide resolution elements less than 0.1 acre in size (422). The possibilities for the use of this equipment in rangeland management are astounding.

On the ground, a portable 2-channel radiometer offers great possibilities for the rapid assessment of dry green standing crop of vegetation (423, 424) and provides rapid estimates of the proportion of dry and green herbage in vegetation samples in the laboratory (425). These advances make the acquisition of basic data on the ground and its use for ground truth much more rapid.

5.2.3 Formulation of Alternatives

After goals and objectives are decided and the inventory, assessment and problem definition completed, the next step in the planning process should be the formulation of alternative solutions which will solve the problems and meet the management objectives. Thus, alternatives are usually groups of specific range improvement and/or ranch management practices.

5.2.4 Available Range Improvement Practices

A comprehensive evaluation of the various technologies for range improvement are presented in the accompanying tables. Various impacts on the ecosystem, on net ranch income, on total society benefits and the constraints on implementation of the practices are evaluated for various manipulations of the Grazing

Food Web in Table 21, for the Vegetation in Table 22, and for the Site Constants and Driving Variables in Table 23. An evaluation of various facilities and equipment is provided in Table 24 and of various chemicals in Table 25.

The areas of optimum combinations of grazing animals; high performance grazing systems with solar-powered high efficiency electric fencing; improved grazing distribution through the use of attractants and repellants; control of competing herbivores, especially nematodes and sucking arthropods; integrated brush management systems, utilizing burning and grazing management, as well as mechanical and chemical control; stand thinning on the shortgrass sod ranges; and deep ripping of claypan complexes show great promise of significant break-throughs. All of them, however, need further research and development. Many other practices are beneficial and should be included in range improvement alternatives.

5.2.5 Selection of Optimum Alternatives

5.2.5.1 Basic Information

A wealth of technical information on the management of rangeland and cropland has been organized in a series of Technical Guides by the Soil Conservation Service in each state (for example, 426). These, in general, follow the guidelines of the National Range Handbook (388). The Extension Services and Experiment Stations of each state in the Great Plains provide published information on range management. Personal technical assistance is available from the Soil Conservation Service upon request or with a Great Plains contract. Cost-sharing of approved practices is available through the Agricultural Conservation Program (427), administered by the Agricultural Stabilization and Conservation Service. County agents and Extension Service specialists are usually available for consultation. Also, agricultural representatives for local banks may be

Table 21. Evaluation of Practices for Manipulating the Grazing Food Web in Range Ecosystems of the Great Plains

	Ecosystem impacts[1] [2]																	
	Vegetation					Managed grazing animals						Net ranch income[5]		Total society benefits[6]		Constraints[7]		
Manipulation[9]	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3]	Competing herbivory	Food intake[4]	Nutritive value of diet[4]	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application[8]
I. Livestock and big game (1, 2, 3, 61, 72)																		
A. Grazing management (1, 2, 3, 29, 33, 61)																		
1. Kind and proportion of grazing animals (1, 3, 20, 21, 22, 23, 34)	M2	L2	M1	M1	U1	S1	S1	S2	L2	M1	M2	3	4	3	4	1	3	1,2
2. Distribution of grazing (1, 3, 13, 14, 25, 26, 27, 28)	M2	L2	M1	M1	M1	M1	M1	M2	L3	M2	M2	3	4	3	4	1	3	2
3. Season of use (1, 3, 36, 37, 38, 62, 155)	L2	L2	L1	L1	U1	L2	L2	L3	L3	L2	L2	3	4	3	4	1	3	2

Table 21. Continued

	Ecosystem impacts[1] [2]											Net ranch income[5]		Total society benefits[6]		Con-straints[7]		
	Vegetation					Managed grazing animals												
Manipulation[9]	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3]	Competing herbivory	Food intake[4]	Nutritive value of diet[4]	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application[8]
4. Grazing system (compared with continuous seasonal grazing) (1, 2, 4, 6, 16, 24, 29, 31, 39, 40, 41, 59, 61)																		
Deferred systems	M3	L3	M1	L1	U1	-S1	-S1	-M2	M3	L2	M2	3	3	3	3	1	3	2
Continuous and deferred systems	M2	L2	M1	L1	U1	S1	S1	S2	L2	L2	M2	3	3	3	3	1	3	2
Rested systems	M3	L3	M1	L1	U1	-S1	-S1	-S2	M3	L2	M2	2,3	2,3	3	3	1	3	2
High performance systems	L1	L1	L1	L1	U1	M1	M1	M1	L1	L1	L1	U	4	U	4	1,5	3	1

Table 21. Continued

	Ecosystem impacts[1/] [2/]											Net ranch income[5/]		Total society benefits[6/]		Constraints[7/]		
	Vegetation					Managed grazing animals												
Manipulation[9/]	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3/]	Competing herbivory	Food intake[4/]	Nutritive value of diet[4/]	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application[8/]
5. Stocking rate (heavy compared with moderate) (4, 5, 6, 7, 8, 9, 10, 11, 15, 30, 35, 41, 58, 65, 66, 67, 68, 69, 70)	-L3	-L3	-S1	-S1	U1	-L2	-L2	-L3	M3	-L3	-L3	4	4	4	4	1	3	2
II. Competing herbivores (29, 42, 43, 44, 45, 46, 47, 48, 49, 50, 52, 87)																		
A. Nematodes (42, 43, 44, 60)	-L1	U1	-M1	-M1	--	U1	U1	-S1	-L1	U1	-L1	1	4	1	4	5	4	1
B. Sucking arthropods (45, 46, 48, 49)	-L1	U1	-M1	U1	--	U1	U1	-S1	-L1	U1	-L1	1	4	1	4	5	4	1
C. Chewing arthropods (45, 47, 50, 63, 64)	-M2	-M1	-M1	U1	--	-M1	-M1	-M1	-L1	-M1	-M2	1	4	1	4	5	2	2

Table 21. Continued

	Ecosystem impacts1/ 2/											Net ranch income5/		Total society benefits6/		Con-straints7/		
	Vegetation					Managed grazing animals												
Manipulation9/	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG3/	Competing herbivory	Food intake4/	Nutritive value of diet4/	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application8/
D. Rodents and rabbits (1, 3, 50, 51, 52, 53, 54, 55, 56, 57, 93)	-L2	-L2	-M1	U1	--	-L1	-L1	-L1	-L1	-L1	-L2	4	4	3	4	2	1,2	2
III. Predators (optimum density compared with low density)(73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86)	MI2	MI1	MI1	MI1	-M2	MI1	MI1	MI1	MI2	MI1	MI2	3	4	3	3	1	1,2	2
IV. Other animals(87, 88, 89, 90, 91, 92, 93, 94, 101)																		
A. Rare species managed for preservation (88, 89, 92, 93)																		
1. Black-footed ferret	-LI1	-LI1	-MI1	-MI1	-MI1	-LI1	-LI1	-LI1	-LI1	-LI1	-LI1	1	1	2	2	1	1	2

Table 21. Continued

	Ecosystem impacts 1/ 2/																	
	Vegetation					Managed grazing animals						Net ranch income 5/		Total society benefits 6/		Con-straints 7/		
Manipulation 9/	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG 3/	Competing herbivory	Food intake 4/	Nutritive value of diet 4/	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application 8/
2. Swift fox	-MI1	-MI1	-MI1	-MI1	-MI1	-MI1	-MI1	-MI1	-MI1	-MI1	-MIL	1	1	2	2	1	2	2
B. Game species (90, 91, 92, 94, 95, 96, 97, 98, 99, 100, 101, 102)	S1	S1	S1	S1	S1	U1	U1	U1	U1	S1	-S1	1	3	2	2	1	1,2	2
C. Other (87, 92, 94, 103)	S1	S1	S1	S1	S1	U1	U1	U1	U1	S1	-S1	1	1	2	2	1	1,2	1

1/ Magnitude of ecosystem impacts (- indicates decrease in amount or quality; no sign indicates increase; 0 no change).
S = Small
M = Intermediate
L = Large
U = Unknown (little or no data to support inferences)

2/ Status of knowledge
1 = None or small
2 = Significant, but incomplete
3 = Extensive

3/ Ratio of above-ground to below-ground net primary production.

Table 21. Continued

4/Selected references: 72, 189, 190, 191.

5/Effect on net ranch income with application of current knowledge and the potential for increase with additional knowledge:
1 = Costs greater than expected returns
2 = Costs greater than expected returns, but of long-term ecological and economic benefit
3 = Expected returns greater than costs
4 = Expected returns much greater than costs
U = Unknown (little or no data to support inferences)

6/Total society benefits with application of current knowledge and potential for increase with additional knowledge:
1 = Costs greater than expected benefits
2 = Costs greater than expected benefits, but viewed as of considerable social or ecological value
3 = Expected benefits greater than costs
4 = Expected benefits much greater than costs
U = Unknown (little or no data to support inferences)

7/Current economic and/or social constraints to manipulation
1 = None or insignificant
2 = Legal and/or policy
3 = Social (e.g. community pressure, inadequate education)
4 = Legal and social
5 = Economically infeasible

8/Status of application:
1 = None or very limited
2 = Significant, but incomplete
3 = Extensive

9/Comments

I. Livestock and big game: These two classes of grazing animals we considered together here as their impacts on the ecosystem are nearly identical.

A. Grazing management: Grazing animals are powerful tools for manipulating the ecosystem for increased productivity and quality. Topics are listed below in the order in which they must be considered.

1. Kind and proportion of livestock: Reference here is to the selection of optimal animal species and combinations of species to more fully utilize the diversity of plant species and topographic positions. This practice is especially important in Texas savanna.

Table 21. Continued

2. Distribution of grazing animals: Improvements to promote more uniform distribution over the range include attractants (water developments, salting, shade placement, fertilization, selective burning, etc.), repellants and forced distribution (cross-fencing, drift fencing, herding, etc.).

3. Season of use: Animal performance is maximized when range forage is grazed at its most nutritive and productive stage. Damage to range plants is minimized when grazing occurs during dormancy.

4. Grazing systems: Deferred and rested systems are mainly directed to range improvement. Continuous and high performance systems give better animal response.

5. Stocking rate: Wise stocking rate decisions presuppose decisions made on the items above and are vital for most profitable ranching. Data are abundant. References are given for long-term studies in the Great Plains.

II. Competing herbivores: Non-managed herbivores consume major portions of net primary production (NPP), reducing productivity and quality of Great Plains rangelands and competing directly with livestock and game for the energy stored in plant tissues.

A. Nematodes: Major consumers of below ground NPP. Use of nematicides has resulted in large short-term productivity increases. Few data are available on ecosystem responses to control measures.

B. Sucking arthropods: Inconspicuous grazers that consume large quantities of NPP. Their presence has been largely ignored.

C. Chewing arthropods: These are often conspicuous because of localized eruptive populations. Normally, competition from these is less than once thought. Manipulation in build-up areas can alleviate their major competive role.

D. Rodents and rabbits: Usually only minor competitors for forage on ranges, except in older prairie dog towns. Eruptive populations can incur major damage and largely exclude other uses from rangelands. Legal restrictions on use of rodenticides has recently accentuated this competitive influence.

III. Predators: Complex interactions with competing herbivore populations (e.g. rodents and rabbits) and livestock and big game. Predators reduce competition from rodents and rabbits, but also may prey upon livestock, big game, and other game. Largest conflict is with sheep, goats, deer and antelope in areas with few alternate food sources. Arthropod and nematode predators are important but are generally not managed and are not considered here.

IV. Other animals: Effects of these species on the ecosystem is generally indirect and usually minor, although black-footed ferret and swift fox preservation through protection of prairie dog colonies may have large negative impacts. If densities become great, impact is likely to be positive. Biological control of prairie dogs by release of captive swift fox has been suggested for control of expanding prairie dog populations. The impact of the management of other threatened or endangered species has little impact on rangelands of the Great Plains.

Table 22. Evaluation of Practices for Manipulating the Vegetation in Range Ecosystems of the Great Plains

	Ecosystem impacts[1] [2]																	
	Vegetation					Managed grazing animals						Net ranch income[5]		Total society benefits[6]		Constraints[7]		
Manipulation[9] (Manipulations in I, II and III are used to reach IV.)	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3]	Competing herbivory	Food intake[4]	Nutritive value of diet[4]	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application[8]
I. Plant control																		
A. Grazing management (designed for plant control) (1, 3, 50, 154, 155, 156, 157)	-S2	L2	-S1	-S1	U1	S1	S1	S1	-S1	-S1	-S1	3	4	3	4	1	3	1,2
B. Biological control of exotic species (1, 3, 50, 159, 160, 161, 163)	S2	M2	S1	U1	U1	S1	S1	S1	S1	-S1	S1	2	4	2	4	5	2	1
C. Biological control of native species (1, 3, 50, 158, 162, 257, 258, 259)	S1	S1	S1	U1	U1	S1	S1	S1	S1	-S1	S1	2	3	2	3	5	1	1
D. Mechanical control (1, 3, 50, 163, 164, 165, 166, 167, 168)	-M2	L2	-S1	U1	U1	S1	S1	S1	-S1	-S1	-M1	3	3	3	3	1	3	3

Table 22. Continued

Manipulation[9] (Manipulations in I, II and III are used to reach IV.)	Ecosystem impacts[1] [2]											Net ranch income[5]		Total society benefits[6]		Constraints[7]		
	Vegetation					Managed grazing animals												
	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3]	Competing herbivory	Food intake[4]	Nutritive value of diet[4]	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application[8]
E. Chemical control (1, 3, 50, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180)	S2	L2	S1	S1	U1	S1	S1	S1	-S1	-S1	S1	1,3	3	1,3	3	1	2	3
F. Integrated brush management system (163)	M2	L2	S1	S1	U1	S1	S1	S1	-S1	-S1	S1	3	4	3	4	1	3	1
II. Range interseeding																		
A. Climax dominants (50, 181, 182, 184, 186, 187, 188)	S2	M1	S1	M1	U1	S1	S1	S1	-S1	S1	S2	1,3	3	1,3	3	1	3	2
B. Alfalfa (50, 182, 183, 184, 185)	M2	M1	S1	M1	U1	M1	M1	M1	-S1	S1	M2	1	U	1	U	1	1	1
III. Stand thinning (71, 147)	M1	M1	U1	M1	U1	M1	S1	S1	M1	S1	S1	1	4	1	3	1	3	1
IV. High range condition (compared with low, under proper use)	L3	L3	S1	L2	S2	S2	S2	S2	M2	L3	L3	4	4	4	4	1	3	2

Table 22. Continued

[1] Magnitude of ecosystem impacts (- indicates decrease in amount or quality; no symbol indicates increase; 0 no change).
S = Small
M = Intermediate
L = Large
U = Unknown (little or no data to support inferences)
I = Indirect impact

[2] Status of knowledge
1 = None or small
2 = Significant, but incomplete
3 = Extensive

[3] Ratio of above-ground to below-ground net primary production.

[4] Selected references: 72, 189, 190, 191.

[5] Effect on net ranch income with application of current knowledge and the potential for increase with additional knowledge:
1 = Costs greater than expected returns
2 = Costs greater than expected returns, but of long-term ecological and economic benefit
3 = Expected returns greater than costs
4 = Expected returns much greater than costs
U = Unknown (little or no data to support inferences)

[6] Total society benefits with application of current knowledge and potential for increase with additional knowledge:
1 = Costs greater than expected benefits
2 = Costs greater than expected benefits, but viewed as of considerable social or ecological value
3 = Expected benefits greater than costs
4 = Expected benefits much greater than costs
U = Unknown (little or no data to support inferences)

[7] Current economic and/or social constraints to manipulation
1 = None or insignificant
2 = Legal and/or policy
3 = Social (e.g. community pressure, inadequate education)
4 = Legal and social
5 = Economically infeasible

Table 22. Continued

[8] Status of application:
1 = None or very limited
2 = Significant, but incomplete
3 = Extensive

[9] Comments: The manipulations listed must be used in conjunction with wise grazing management in order to be effective. After each treatment is completed the result will be higher range condition and improved productivity and quality as noted in item IV. Other ratings are for the improvement period.

I. Plant control: Past emphasis has been on mechanical and chemical control. Recent legal restrictions on herbicide use and costs of mechanical and herbicide applications have improved the attractiveness of grazing management and biological control.

A. Grazing management: A form of biological control exploiting selective grazing habits. Target species must be palatable to the grazer at a season when the target species is easily damaged by grazing. This practice has been used very effectively along with others in Texas savanna.

B and C. Biological control: Most useful when the problem plant is an exotic which has been freed of its enemies when introduced and the enemies can be screened and introduced in the new environment. Requires large screening effort. Propagation of diseases and parasites of native problem plant species has been much less effective.

D. Mechanical control: Generally drastically disturbs the ecosystem and may require full seeding following treatment. Important on extremely deteriorated ranges, where conversion from brushland to grassland is necessary. Site potential must be high to pay for treatment, except in very extensive applications.

E. Chemical control: Effective, usually selective methods of control using both air and ground application. Legal and environmental policy restrictions have limited available herbicides for use, while newly developed herbicides are often beyond economic feasibility for extensive use.

F. Integrated brush management system: This approach has been used mainly in Texas savanna and incorporates all methods including burning in a unified control plan.

II. Range interseeding: Introducing a desired plant species into range without destroying the plant community. Interseeding alfalfa has been partially successful, but complicates management. Combined effects of seeding and tillage increase its value. Most useful on erodible sites where removal of the cover is hazardous or where seeding is needed but the original community should be preserved. Full seeding is a replacement of the plant community and is not considered here.

Table 22. Continued

III. Stand thinning: Chemical or mechanical thinning of shortgrass sod shows potential for increasing above-ground standing crop and encouraging erect growth of shortgrasses enabling more livestock use of otherwise unavailable herbage.

Table 23. Evaluation of Practices for Manipulating Site Constants and Driving Variables in Range Ecosystems of the Great Plains

	Ecosystem impacts[1] [2]											Net ranch income[5]		Total society benefits[6]		Con-straints[7]		
	Vegetation					Managed grazing animals												
Manipulation[9]	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3]	Competing herbivory	Food intake[4]	Nutritive value of diet[4]	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application[8]
I. Weather modification (104, 105, 106, 107, 108, 109, 110, 111)	M1	M1	M1	M1	U1	S1	S1	S1	M1	M1	M1	1	4	1	4	5	4	1
II. Fire control (2, 31, 50, 112, 113, 114, 115, 116)																		
A. Controlled burning																		
1. Plains grasslands	-M1	M1	U1	U1	U1	S1	S1	S1	-S1	S1	-M1	1	3	1	3	1	3	1
2. Prairie	M3	L3	S1	U1	U1	M2	M2	M2	M2	L3	L3	3	4	3	4	1	3	2
3. Texas savanna and shinnery	-S3	L3	S1	U1	U1	M2	M2	M2	M2	L3	M2	3	4	3	4	1	3	2
B. Fire prevention																		
1. Plains grasslands	M3	-M1	U1	U1	U1	-S1	-S1	-S1	-S1	-S1	M1	3	3	3	3	1	3	3
2. Prairie	-M3	-L3	U1	U1	U1	-M2	-M2	-M2	-M2	-M2	M3	1	1	1	1	1	1	2
3. Texas savanna and shinnery	M3	-L3	U1	U1	U1	-M2	-M2	-L2	-L2	-M2	-M2	1	1	1	1	1	1	2

Table 23. Continued

Manipulation[9]	Ecosystem impacts[1] [2]											Net ranch income[5]		Total society benefits[6]		Constraints[7]		Status of application[8]
	Vegetation				Competing herbivory	Managed grazing animals				Ecological diversity	Watershed value							
	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3]		Food intake[4]	Nutritive value of diet[4]	Gain per animal	Gain per area			Current knowledge	Potential	Current knowledge	Potential	Economic	Social	
III. Soil																		
A. Nitrogen fertilization (31, 50, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130)	L3	-L3	L1	M1	U1	S3	S3	S3	L3	-L3	M3	1	1	1	1	5	1	1
B. Tillage																		
1. Deep ripping and contour furrowing solodized-solonetz soils (50, 131, 132, 133, 134, 138)	L2	L2	L1	L1	U1	L1	L1	L2	L2	L2	L2	3	4	3	4	1	3	1
2. Deep ripping ordinary uplands (50, 134, 135, 136, 137)	M2	M2	M1	L1	U1	S1	O1	S2	M2	M2	M2	1,3	3	3	3	1	3	1

Table 23. Continued

Manipulation[9]	Ecosystem impacts[1] [2]											Net ranch income[5]		Total society benefits[6]		Constraints[7]		
	Vegetation					Managed grazing animals												
	Above ground standing crop	Botanical composition	Net primary productivity	AG:BG[3]	Competing herbivory	Food intake[4]	Nutritive value of diet[4]	Gain per animal	Gain per area	Ecological diversity	Watershed value	Current knowledge	Potential	Current knowledge	Potential	Economic	Social	Status of application[8]
3. Contour furrowing and pitting ordinary uplands (50, 134, 137, 138, 139, 140, 141, 142, 143, 144, 145)	M2	M2	M1	L1	U1	S1	01	S2	L2	M2	M2	3	3	3	3	1	3	2
C. Land form modification(134, 151, 255)	M1	M1	M1	M1	U1	S1	S1	S1	L1	-S1	M1	1	1	1	1	5	3	1
IV. Waterspreading and irrigation(15, 146, 148, 149, 150, 152, 153)	L2	L2	L1	L1	U1	S1	S1	S1	L1	L2	L2	3	4	3	4	1	3	2

---

[1] Magnitude of ecosystem impacts (- indicates decrease in amount or quality; no sign indicates increase; 0 no change).

S = Small
M = Intermediate
L = Large
U = Unknown (little or no data to support inferences)
I = Indirect impact

Table 23. Continued

[2] Status of knowledge
1 = None or small
2 = Significant, but incomplete
3 = Extensive

[3] Ratio of above-ground to below-ground net primary production.

[4] Selected references: 72, 189, 190, 191.

[5] Effect on net ranch income with application of current knowledge and the potential for increase with additional knowledge:
1 = Costs greater than expected returns
2 = Costs greater than expected returns, but of long-term ecological and economic benefit
3 = Expected returns greater than costs
4 = Expected returns much greater than costs
U = Unknown (little or no data to support inferences)

[6] Total society benefits with application of current knowledge and potential for increase with additional knowledge:
1 = Costs greater than expected benefits
2 = Costs greater than expected benefits, but viewed as of considerable social or ecological value
3 = Expected benefits greater than costs
4 = Expected benefits much greater than costs
U = Unknown (little or no data to support inferences)

[7] Current economic and/or social constraints to manipulation
1 = None or insignificant
2 = Legal and/or policy
3 = Social (e.g. community pressure, inadequate education)
4 = Legal and social
5 = Economically infeasible

[8] Status of application:
1 = None or very limited
2 = Significant, but incomplete
3 = Extensive

Table 23. Continued

[9] Comments: The manipulations listed must be used in conjunction with wise grazing management in order to be effective.

I. Weather modification: Weather modification with present technology may increase precipitation 10 to 15% over the Great Plains. Effects have been inferred from irrigation studies and vegetation studies under variable amounts of precipitation. Long-term impacts on vegetation and on the grazing food webs are unknown.

II. Fire control: Controlled burning is an important range improvement practice on the Prairie and has value for plant control in the Plains grasslands, Texas savanna and shinnery. Fire prevention has greatest value in the xeric portions of the Plains grasslands.

III. Soil manipulation

A. Nitrogen fertilization: Increased cost has made this practice unprofitable. Increases in undesirable vegetation often require plant control as an auxiliary practice. Fertilization with other elements has not been widely used, but may be important locally.

B. Tillage: Improvement of soil water infiltration, amelioration of soil profile restrictions, release of vegetatively-reproducing plant species, impairment of less desirable plant species.

1. Deep ripping and contour furrowing solodized-solonetz soils: Possible dramatic, permanent improvement of otherwise low-producing sites.

2. Deep ripping ordinary uplands: An expensive practice, with high power requirements, intended to improve water infiltration into soil profile. In Plains grasslands encourages vegetative reproduction of desirable rhizomatous grasses, while reducing competition from shortgrasses. Duration of improvement is unknown and probably varies with the clay content of the soil.

3. Contour furrowing and pitting: Rationale similar to 2, but much less expensive. Provides more drastic surface soil disturbance with opportunities to seed in furrows or pits. Effectiveness is generally proportional to disturbance. Soil water relations are much superior to untreated lands. Some resistance of landowners to its use because of land roughness.

C. Land form modification: Land leveling, terracing, bench terracing, generally restricted to climates and soils with high production potentials. Costs are usually prohibitive unless coupled with waterspreading or with a change to cropland. Treatments may be detrimental on shallow or weakly developed soils.

D. Waterspreading and irrigation: Waterspreading can increase forage production many fold economically. Substantial initial investment and lack of information has restricted its use. Limited to areas with sufficient water supply, and site potential. Great value for special-use pastures and haylands.

Table 24. Facilities and Equipment for Managing and Improving Range Ecosystems of the Great Plains

Facility or equipment item[1/]	Status of development[2/]	Extent of application[3/]	Power mover[4/]
I. Facilities and equipment used in grazing management			
A. Fencing(1, 50, 192, 193, 194, 195)			
1. Conventional barbed wire fencing	3	3	
2. Conventional woven wire fencing	3	3	
3. Big game fencing	3	2	
4. Suspension fencing	3	1	
5. Electric, conventional fencing	3	3	
6. Electric, high efficiency fencing	3	1	
7. Solar-powered electric energizer	3	1	
8. Mechanized fence builder	3	1	
9. Antelope pass fencing	3	1	
B. Water developments(1, 50)			
1. Improvement of natural supplies	3	3	
2. Wells, windmill	3	3	
3. Wells, power pumped	3	3	
4. Deep wells	3	1	
5. Reservoirs and dugouts	3	3	
6. Rain catchments	3	1	
7. Storage facilities	3	1	
8. Piping	3	1	

Table 24. Continued

Facility or equipment item[1]	Status of development[2]	Extent of application[3]	Power mover[4]
9. Heaters, propane	3	2	
10. Heaters, solar-powered	2	1	
C. Handling and animal management			
1. Corrals and related facilities	3	3	
2. Portable corrals	3	1	
3. Identification			
a. Fire branding equipment	3	3	
b. Freeze branding equipment	3	2	
c. Ear tags and bands	3	2	
d. Electronic	1	1	
e. Telemetered	3	2	
4. Weighing			
a. Conventional scale	3	2	
b. Electronic, automatic recording	1	1	
5. Windbreaks, shelter, shades	3	2	
II. Equipment used in manipulation of vegetation(1, 50, 163, 164, 195, 196)			
A. Mechanical plant control			
1. Plant root extraction			
a. Root plows	3	2	3
b. Grubbers	3	2	1,2,3
2. Brush clearing			
a. Brush rakes	3	2	1,2,3

Table 24. Continued

Facility or equipment item[1]	Status of development[2]	Extent of application[3]	Power mover[4]
b. Chains and cables	3	2	1,2,3
c. Rails	3	2	1,2,3
3. Choppers and shredders			
a. Rolling choppers	3	2	3,4
b. Rotobeaters and shredders	3	2	1,2,3,4
4. Mowers	3	3	1
5. Handtools	3	3	--
B. Herbicide application			
1. Fixed-wing aircraft sprayers	3	2	--
2. Helicopter boom sprayers	3	2	--
3. Vehicle mounted boom sprayers	3	2	1,2,3
4. Other vehicle mounted applicators	2,3	2	1,2,3
5. Mist sprayers	3	2	1,2,3
6. Subsoil injectors	3	1	1,2,3,4
7. Tree injectors	3	2	--
C. Seeding			
1. Broadcast seeders			
a. Fixed-wing aircraft spreaders	3	2	--
b. Helicopter spreaders	3	2	--
c. Seed dribblers	3	3	3
d. Blower spreaders	3	3	1,2,3
e. Rotary spreaders	3	3	1,2,3
f. Steep slope scarifier-seeder	3	1	4

Table 24. Continued

Facility or equipment item[1/]	Status of development[2/]	Extent of application[3/]	Power mover[4/]
g. Hydraulic seeder-mulchers	3	2	4
h. Grass seeder (spreader with cultipacker)	3	2	1
2. Drills			
a. Grain drills	3	3	1
b. Heavy-duty grain drills (pasture drills)	3	2	1,2
c. Rangeland drills	3	2	3
d. Presswheel drills	3	2	3
e. Seeder for brush-littered range	2	1	3
3. Interseeders			
a. Range interseeders	3	2	1,2,3
b. Tiller seeders	3	1	1,2
c. Interseeder for rocky and brushy areas	3	2	3
4. Others			
a. Sodders	2	1	4
b. Spriggers	2	1	1
c. Tree and shrub planters	3	1	1,2,3
III. Equipment used in manipulation of site constraints and driving variables(1, 50, 195, 196)			
A. Tillage			
1. Seedbed preparation and/or soil treatments			
a. Moldboard plows	3	3	1
b. One-way disc plows	3	3	1

Table 24. Continued

Facility or equipment item[1]	Status of development[2]	Extent of application[3]	Power mover[4]
c. Offset discs	3	3	1,2,3
d. Pitters	3	2	1
e. Land imprinter	3	1	3
f. Chisel plows	3	3	1,2
g. Subsoilers	3	2	1,2,3
h. Rippers	3	2	2,3
i. Contour trenchers	3	2	3
j. Contour furrowers	3	2	1,2,3
k. Rotary tillers	3	1	1,2
2. Secondary seedbed preparation			
a. Sifters	3	2	1,2,4
b. Harrows	3	2	1,2
c. Cultipackers	3	2	1,2
B. Fertilizing and mulching			
1. Fertilizer spreaders	3	3	1,2
2. Granular applicators	3	3	1,2
3. Mulchers and mulch applicators	3	2	1,2.4
4. Mulch incorporators	3	2	1,2
C. Fire management			
1. Ignition devices	3	2	--
2. Fireline plows	3	2	1,2,3

[1] Equipment and facilities are grouped according to their principal use. It is recognized that many have a variety of applications.

Table 24. Continued

[2] Status of development:
1 = Undeveloped
2 = In various stages of development, not yet available for general use.
3 = Fully developed and available for use; refinements may be made in existing equipment.

[3] Extent of optimum application:
1 = None or very limited
2 = Significant, but incomplete
3 = Complete or near complete
4 = Considered obsolete

[4] Power mover used in operation of equipment:
1 = Rear-wheel drive farm tractor
2 = All-wheel drive farm tractor
3 = Crawler tractor
4 = Specialized power supply vehicle

Table 25. Classes of Chemicals for Managing and Improving Range Ecosystems on the Great Plains

Use	Status of development[1]	Extent of application[2]
I. Herbicides (50, 169, 247, 248, 249, 250, 251)		
A. Selective herbicides	3	3
Woody plants	3	3
Herbaceous broad-leaved plants	3	3
Grasses and grass-like plants	3	3
B. Non-selective herbicides	3	3
C. Soil sterilants	3	3
II. Insecticides (45, 50)	3	2
III. Nematicides (43, 60)	2	1
IV. Rodenticides (50, 25, 252)	3	2
V. Attractants and repellants (254)	1	1

[1] Status of development:
1 = Undeveloped
2 = In various stages of development, not yet available for general use.
3 = Fully developed and available for use; production of new formulations is possible.

[2] Extent of optimum application:
1 = None or very limited
2 = Significant, but incomplete
3 = Complete or near complete
4 = Considered obsolete

very helpful. University professors, and research workers publish information, hold field days and answer personal inquiries about range management problems. Private consultants, certified by the Society for Range Management in the range field and by the American Society of Animal Science in the animal field are available. Publications from the Society for Range Management and various popular journals provide information. Sophisticated marketing information is available, some broadcast or telecast and more detail is given in published or wire service format. Detailed weather forecasts are available which are quite reliable for weekly periods and less so for monthly or longer periods. Indeed, a vast storehouse of information is available to the range and ranch manager, most of it free of charge. Unfortunately, many operators do not avail themselves of this information before making crucial decisions in the management of their rangelands.

5.2.5.2 Computational Devices

The electronics industry has made fantastic progress in the past decade in which the cost of a calculator has decreased by 90% in actual dollars. Small hand-held or desk-top programmable calculators are available which will do what sophisticated computers were required to accomplish 20 years ago. These calculators are reasonably priced and have large numbers of complete programs already written. Mini-computers, many of them desk-top in size, are still more powerful.

Large capacity computers are available at many locations over the nation. "Ag-Net" terminals connect many county agent offices in the five northern Great Plains states with a computer in Lincoln, Nebraska with a wide range of agricultural programs available. Forest Service offices are connected with a large computer in Ft. Collins, Colorado with 200 programs available for assistance in land management decision (265). Various offices of the Bureau of Land Management are connected with a computer at the Denver Federal Center which can provide linear programming and other programs. Each of the state offices of the Soil Conservation Service in the northern plains is connected with a computer in Ft. Collins. Each of the State Universities, Experiment Stations and Extension Services have access to computers. Various financial institutions both public and private have computer-assisted decision-making tools.

5.2.5.3 Mathematical Models and Procedures

Various services are available, all of them starting with computerized records as the basis of computation. Assistance in setting up these records is available. Programs to aid in decision-making are widely available from ranch budgeting to more sophisticated techniques, which may be categorized as agricultural production functions (406), operations research methods (407), optimization models (261) and simulation models (408).

Van Dyne and Abramsky (261) provided an overview of optimization and simulation modeling in agricultural systems. Optimization models are the most useful for guidance in decision-making. The simplest of the optimization models is linear programming, which is not only linear, but also static and deterministic. (Rangeland examples: 409, 410, 268, 271, 414, also examples in 18.) The most comprehensive linear programming approach to range and ranch planning is COPLAN (411, 19, 269) available from the Range Science Department, Colorado State University, Ft. Collins, Colorado. Linear programming has been extended to sequential operations (17).

Van Dyne used non-linear programming in a forage allocation problem (20, 21, 413) with linear constraints and a non-linear objective function, with sensitivity analyses included, using 10 plant groups and 4 animal species. This was later expanded to multiple seasons with random variation included. The model is classified as non-linear (quadratic), multi-season, weighted, and stochastic (413).

Linear programming has only one goal, such as maximizing profit or minimizing cost. However, rangeland management, especially on public lands, but also on private ranches, often has multiple objectives. Goal programming (272, 273) is similar to linear programming, but permits solution for multiple goals.

The development of ecosystem-level simulation models has been reviewed by Van Dyne (263) and by Wiegert (412). These models simulate the operation of an ecosystem and vary greatly in degree of complexity and mathematical sophistication from a very simple non-mechanistic model of the effect of grazing on vegetation (267) to a comprehensive total system model, such as ELM 1973, developed under the Grassland Biome project (415, 262).

Thus far, simulations have been used very little for guidance in management decisions. However, a number of hypotheses have been generated and tested by the ELM model which have provided insights and further hypotheses for field testing (for example, 264, 402, 416). The technique of combining simulation and optimization models (266) offers much promise for guidance in decision-making for rangelands.

The growth of technology in decision-making tools is proceeding rapidly. Linear programming models are ready for use now. The more sophisticated optimization techniques should be in application in a few years. Simulation-optimization models may not be operational for a decade or more. Preparation of future range and ranch managers to assimilate these advanced tools into their decision-making skills should begin now.

6. RANCHING, KINDS OF LAND, AND LAND CONVERSIONS

6.1 Kinds of Businesses Using Rangelands

Approximately 95% of the rangeland in the Great Plains region is in private ownership. Much of this land occurs intermingled with cropland and managed in different kinds of agricultural enterprises. The structure of agriculture in the Great Plains states is summarized for 1969 in Table 26 taken from Boykin (449). Ranches are businesses which derive most of their income from the sale of grazing animals and the animals get most of their food from native range. They differ from livestock farms where animals get most of their food from cropland. The ranches are predominantly cow-calf, selling calves at weaning with some cow-yearling, some yearling operations. Sheep are mainly of importance in the Edwards Plateau (Texas savanna) and in the Northern Plains (Plains grassland). Goats are of importance only on the Edwards Plateau.

Non-agricultural uses of privately-owned rangeland occupy small acreages, but may be very important. Probably the most important of the non-agricultural businesses is coal mining. The largest area of strippable coal reserves in the nation (36.8 million hectares) occur in the Northern Great Plains states of Montana, Wyoming, North Dakota, and South Dakota. About 70% of these are on rangeland (461). The Northern Great Plains Resources Program categorized three levels of development: CDP-I, the minimum reasonable rate of coal development; CDP-II, an intermediate level; and CDP-III, the maximum reasonable rate of coal development (460). Current levels of coal development are between CDP-II and CDP-III. At this rate the amount of rangeland affected will be between 2,632 and 5,791 ha by 1980, 8,343 and 18,711 by 1985 and 23,004 and 90,679 ha by 2000. The five counties of Rosebud and Bighorn in Montana, Campbell in Wyoming and Oliver and Mercer in North Dakota have approximately

Table 26. Commercial Farms by Enterprise by Size, Kind of Land, Proportion of Beef Cattle and Size Group of Beef Cattle for Northern and Southern Plains States, 1969 Census (Adapted from Boykin, 449)

Region and Item	Kind of farm						
	Cash grain	Cotton	General	Livestock		Other	All
				Farms	Ranches		
Northern Plains[1]							
All farms, %	38	0	8	44	4	7	100
Acreage[2]	677	0	665	753	2,741	454	772
Cropland, %	84	--	72	56	9	74	61
Pasture, %	16	--	28	44	91	26	39
Beef cows, % of all	17	--	7	58	12	6	100
Farms with beef cows, %							
<50	85	0	75	64	41	77	71
50-199	15	0	24	33	42	22	27
200-999	t	0	1	3	16	1	2
>1000	0	0	0	t	1	0	t
Southern Plains							
All farms, %	16	10	9	29	25	12	100
Acreage	638	490	571	489	2,153	324	914
Cropland, %	79	82	66	51	7	48	31
Pasture, %	21	18	34	49	93	52	69
Beef cows, % of all	6	2	6	27	51	9	100
Farms with beef cows, %							
<50	83	92	83	73	54	65	69
50-199	15	7	16	25	37	32	27
200-999	2	1	1	2	8	3	4
>1000	0	0	0	t	1	t	t

---

[1] Northern Plains states are North Dakota, South Dakota, Nebraska and Kansas. Southern Plains states are Oklahoma and Texas.

[2] Acreage was approximated by totaling cropland and pastureland.

one-half of the rangeland that will be affected by coal development in the Northern Great Plains.

Ranching and mining, as well as all of the other businesses using the rangelands of the Great Plains, are being strongly affected by global and national trends over which they have no control.

6.2 Global and National Trends Affecting Businesses Using Great Plains Rangelands

6.2.1 Population

World population is now at 4.5 billion and increasing at the rate of 1.78% (0.68% per year in the more developed regions and 2.18% in the less developed regions; Table 27). By 2000 the moderate projection (455) predicts a world population of 6.35 billion with 21% in the more developed and 79% in the less developed regions and growing at the rate of 1.70% per year (0.51% in more developed and 2.02% in less developed regions). Distribution of population and population growth by countries is shown in Fig. 55 (455). The very large number of children and people of child bearing age in the world (Fig. 56, 455) make it unlikely that population growth can be slowed quickly. The average crude birth rate for the less developed regions was 35.9 per thousand with some countries exceeding 45.0. Even with a strong family planning effort it would require 38 years to reduce the crude birth rate from 45 to a replacement level of about 15 per thousand (Table 28, 455). Although the Global 2000 report did not document trends beyond 2000, they conclude, "At present and projected growth rates, the world's population would reach 10 billion by 2030 and would approach 30 billion by the end of the twenty-first century. These levels correspond closely to estimates by the U. S. National Academy of Sciences of the maximum carrying capacity of the entire earth" (456).

Table 27. Bureau of Census Estimates and Projections, Medium Series, Summary Data, 1975-2000 (455)

	Population	Percent of world population	Annual percent growth[1]
	(Population in billions)		
1975 World	4.09	--	
More developed regions	1.13	28	
Less developed regions	2.96	72	
1980 World	4.47	--	1.78
More developed regions	1.17	26	0.68
Less developed regions	3.30	74	2.18
1985 World	4.88	--	1.77
More developed regions	1.21	25	0.70
Less developed regions	3.67	75	2.14
1990 World	5.34	--	1.78
More developed regions	1.25	23	0.66
Less developed regions	4.09	77	2.14
1995 World	5.83	--	1.77
More developed regions	1.29	22	0.59
Less developed regions	4.54	78	2.11
2000 World	6.35	--	1.70
More developed regions	1.32	21	0.51
Less developed regions	5.03	79	2.02

---

[1] Annual percent growth for the preceding 5-year period.

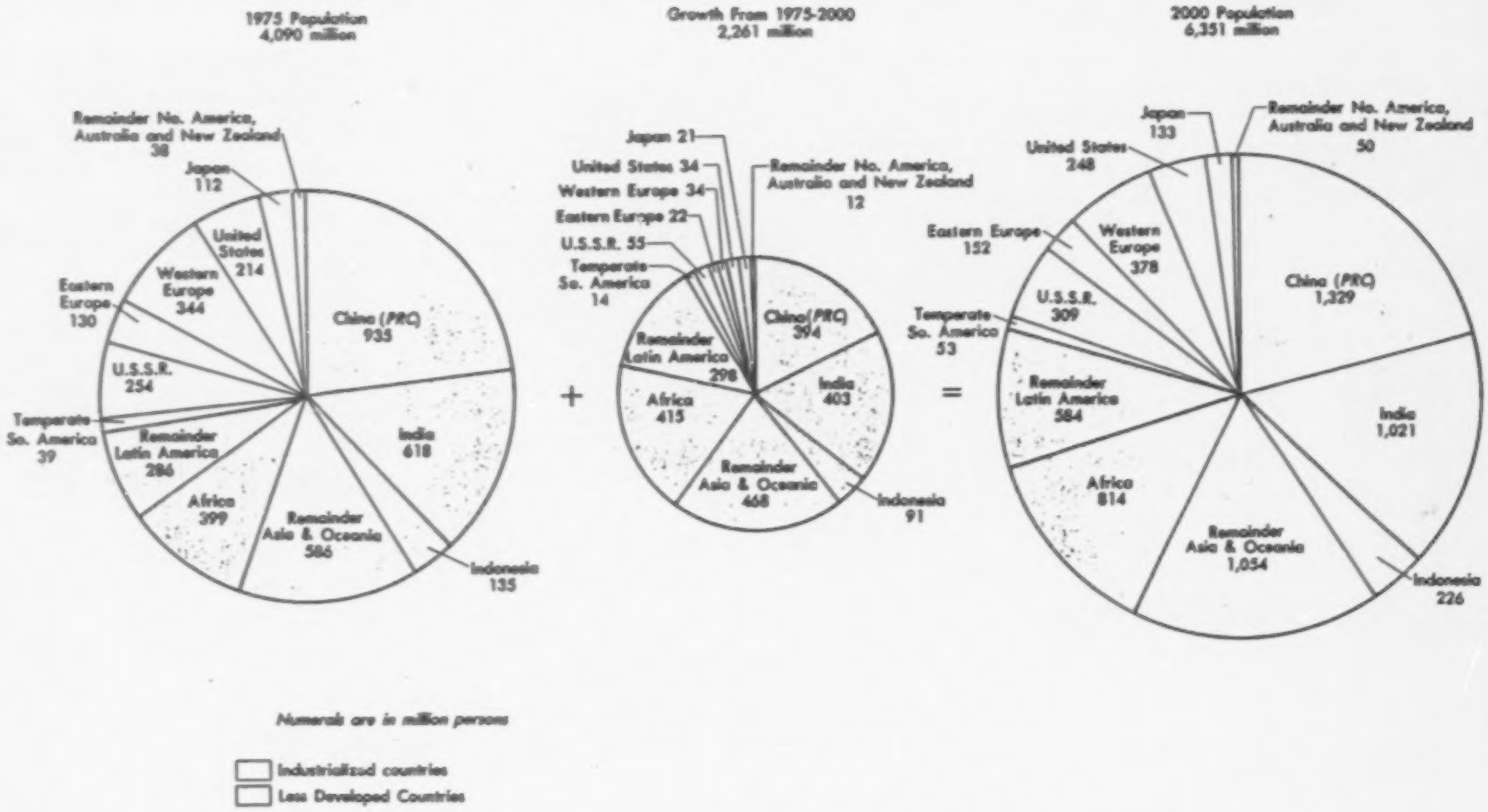


Figure 55. Twenty-five years of world population growth, medium series (455).

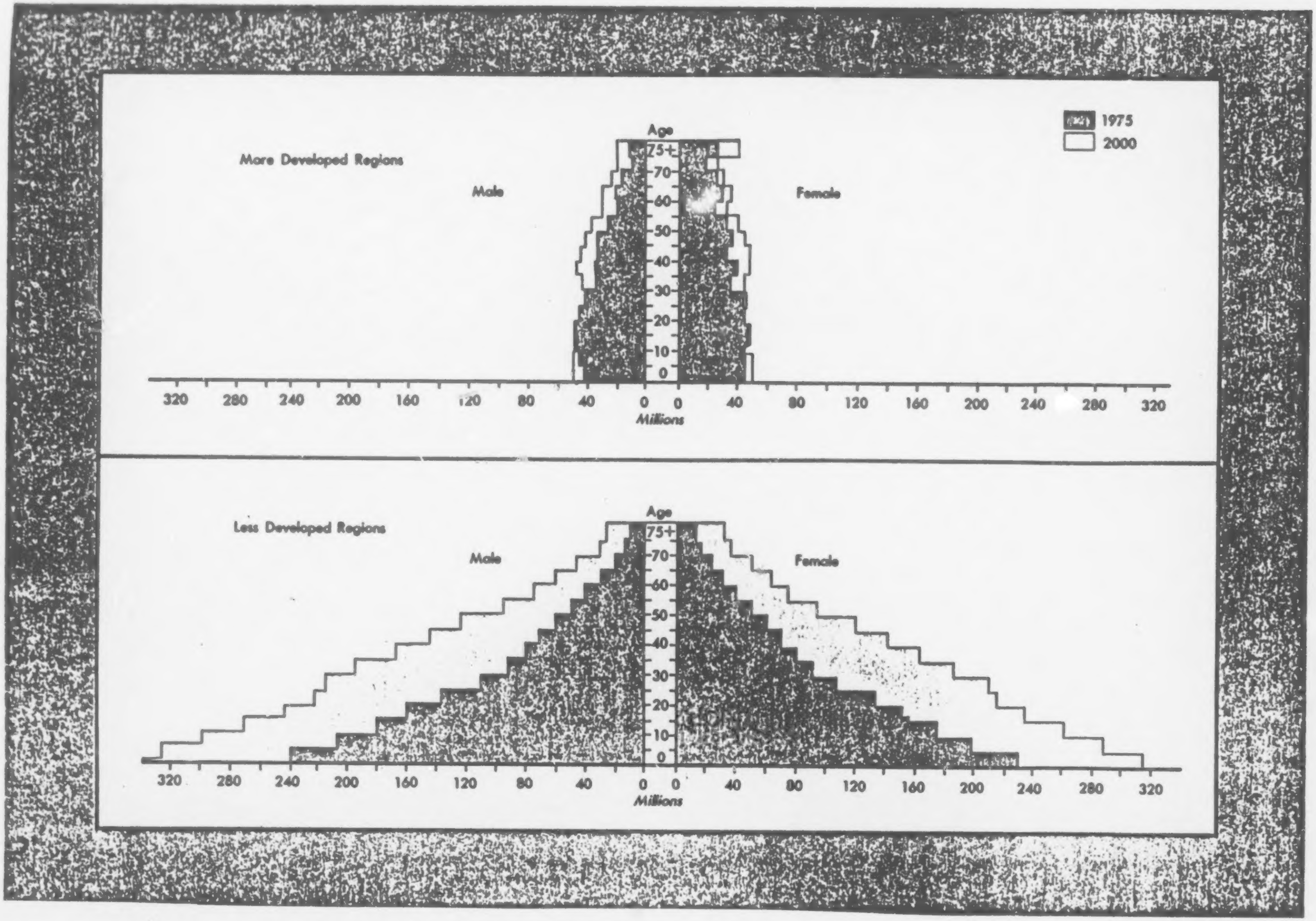


Figure 56. Age-sex composition of population, medium series, 1975 and 2000 (455).

Table 28. Census Bureau Annual Decline in Crude Birth Rate (455)

Crude birth rate (per thousand)	Strength of family planning effort			
	Strong	Moderate	Weak	None
40-44	8.0	10.0	17.0	0.25
35-39	6.0	8.0	12.0	0.25
30-34	5.0	7.0	10.0	0.20
25-29	5.0	8.0	12.0	0.20
20-24	6.0	10.0	17.0	0.25
15-19	8.0	15.0	20.0	0.25
Time required to decline from CBR = 45 to CBR = 15 (years)	38.0	58.0	88.0	135

The United States population of about 220 million is growing at the rate of about 0.7% per year declining to 0.4% per year by 2000, with a crude birth rate of about 16 declining to less than 14 by 2000. However, migration is an important factor. Without migration U.S. population would be about 248 million in 2000, but with migration is expected to be about 260 million.

6.2.2 Gross National Product per Capita

The world gross national product per capita was $1,473 in 1975 and expected to grow by 2.26% per year in the next decade and 1.53% per year in the next 15 years, reaching $2,311 in 1975 dollars in 2000, according to the medium projection (Table 29, 455). While the less developed countries are making substantial growth, the more developed countries of the world are growing faster, and thus widening the gap. While the U. S. growth rate is slightly exceeded by western Europe and some other nations, the U. S. G.N.P. per capita is very high and is projected to grow rapidly, reaching $14,212 in 1975 dollars by the year 2000.

6.2.3 Effect of Growth of Population and Gross National Product per Capita

6.2.3.1 Food and Fiber

The combined effect of population growth and growth in per capita G.N.P. is to increase the demand for food, clothing, shelter and, indeed, all of the resources of the environment. To merely sustain 6.3 b people at present levels would require a 60% increase in production from agriculture, fisheries, and forests (457). To meet the further demand of increased well-being related to G.N.P. per capita will require an 80% increase in production by 2000. Total food consumption is expected to be 94% above the 1969-71 level by 2000 (455). The United Nations World Food Conference in 1974 reported that the demand for

Table 29. Gross National Product per Capita (1975) with Predictions for 1985 and 2000 for More Developed and Less Developed Countries and the United States (455)

	1975	Average annual growth rate, 1975-85, %	1985	Average annual growth rate, %	2000
World	1,473	2.26	1,841	1.53	2,311
More developed countries	4,325	3.16	5,901	2.45	8,485
Less developed countries	382	2.75	501	2.13	587
United States	7,066	3.28	9,756	2.54	14,212

food in the markets of the developing countries was increasing by as much as 3.6% per year and set a target of 4% per year increase (double in 18 years) in agricultural production in these countries (458).

The Global 2000 report shows increases in per capita consumption of grain for feed and meat to increase substantially in both the LCDs and Industrialized Nations (Table 30) with only small increases in per capita increases in grain consumption for food in the LCDs and slight decreases in the INs. The projection of total grain production shows large increases in production and consumption (Table 31). Although the industrialized nations, especially the United States, will continue to export grain to the centrally-planned economies and the developing nations, increases in grain production are expected to slightly exceed increases in consumption in the developing countries. This assumes increased grain production (Fig. 57, 455) on only slightly increased actual acres of arable land, and on greatly decreased arable land per capita (Fig. 58, 455). Greatly increased intensity of cultural energy inputs (Fig. 59, Fig. 60, Fig. 61) for more intensive agricultural production are assumed. Capital requirements for this kind of agriculture are very high. Bauman (459) comments that "The green revolution not only made the rich richer and the poor poorer by a concentration of the means of production..., but also created an enormous increase of energy consumption....A rethinking of agro-systems is necessary..." The non-OPEC developing countries are being hit harder than others by increasing oil prices with no recourse but to borrow very large amounts of money from international banks which they may be unable to repay.

The modern food production system is an energy sink which requires relatively cheap sources of cultural energy or else must result in the production of very expensive food and other products. According to one source, the U. S.

Table 30. Grain and Meat Consumption per Capita, 1970 with Projections (455)

	Year or Period	Consumption, kg		Average annual percent growth	
		Less developed countries	Industrialized nations	Less developed countries	Industrialized nations
Grain for food	1970	155.9	172.5	--	--
	1985	181.7	170.2	--	--
	1970-1985	--	--	1.0	-0.1
	2000	188.6	163.4	--	--
	1985-2000	--	--	0.2	-0.3
Grain for feed	1970	17.0	362.0	--	--
	1985	19.4	440.0	--	--
	1970-1985	--	--	0.9	1.4
	2000	23.8	585.6	--	--
	1985-2000	--	--	1.3	1.9
Meat	1970	3.2	67.6	--	--
	1985	3.7	82.9	--	--
	1970-1985	--	--	1.0	1.4
	2000	4.6	94.3	--	--
	1985-2000	--	--	1.5	0.9

Table 31. Projections of Grain Production, Consumption and Trade by Region (World Production, 1969-71 = 100[1])

Region		1985	2000	Increase	Linear increase, % per year
World	Production	143.9	195.6	51.7	3.4
	Consumption	143.9	195.6	51.7	3.4
Industrialized nations	Production	49.4	64.0	14.6	2.0
	Consumption	42.9	56.8	13.9	2.2
	Trade	+6.5	+7.2	0.7	
Centrally-planned countries	Production	51.1	65.1	14.0	1.4
	Consumption	53.7	68.4	14.7	1.8
	Trade	-2.6	-3.3		
Less developed countries	Production	43.4	66.5	23.1	3.6
	Consumption	47.2	70.4	23.2	3.3
	Trade	-3.8	-3.9		
United States	Production	27.1	36.9	9.8	2.4
	Consumption	18.5	25.4	6.9	2.5
	Trade	+8.6	+11.5		

---

[1] Calculated from Table 6-5 (455) and expressed on the basis of the world grain production in 1969-71 (1109.2 million metric tons) as 100.

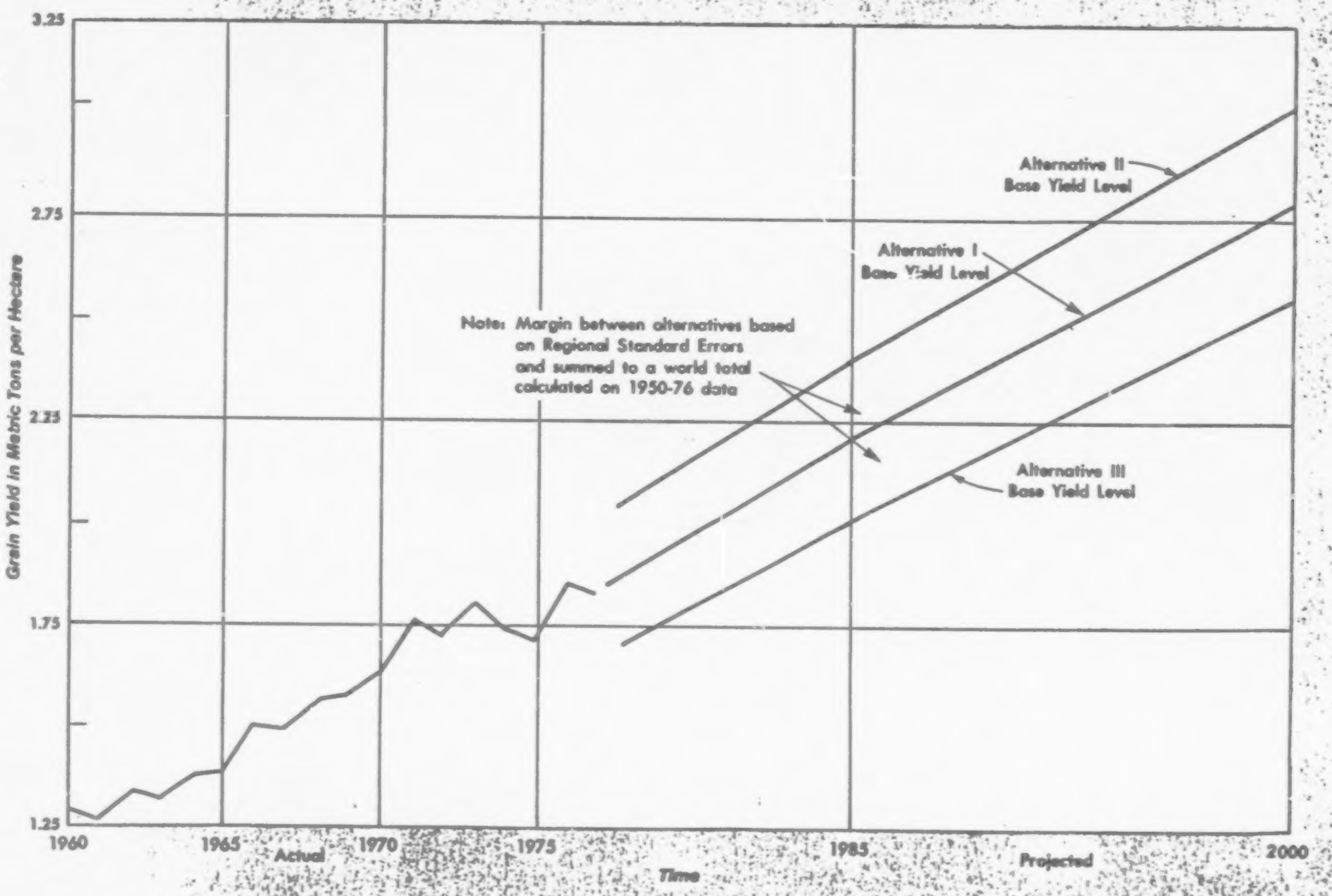


Figure 57. World grain yeilds, actual and projected under Alternatives I, II, III (455).

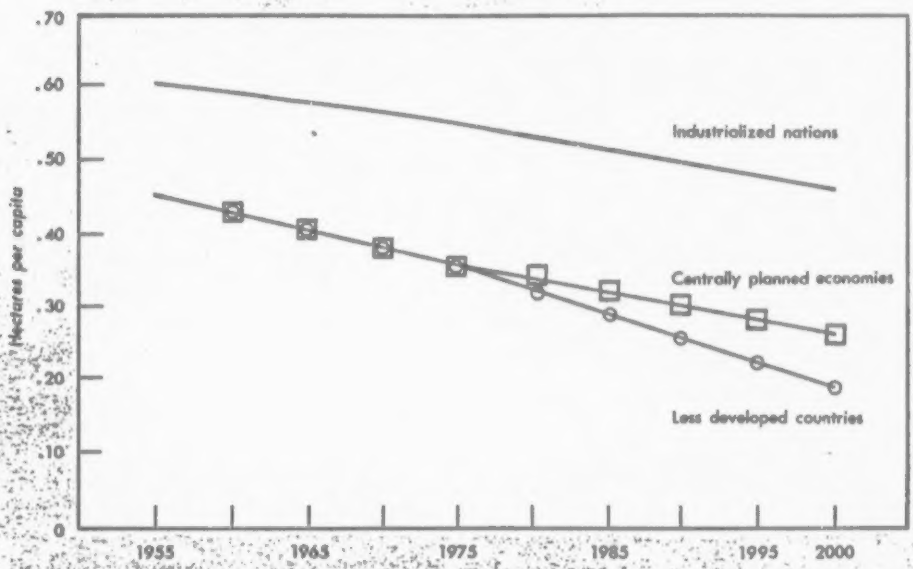


Figure 58. Arable land per capita, 1955, 1975, and 2000. (From Chapter 6, Table 6-13, 455).

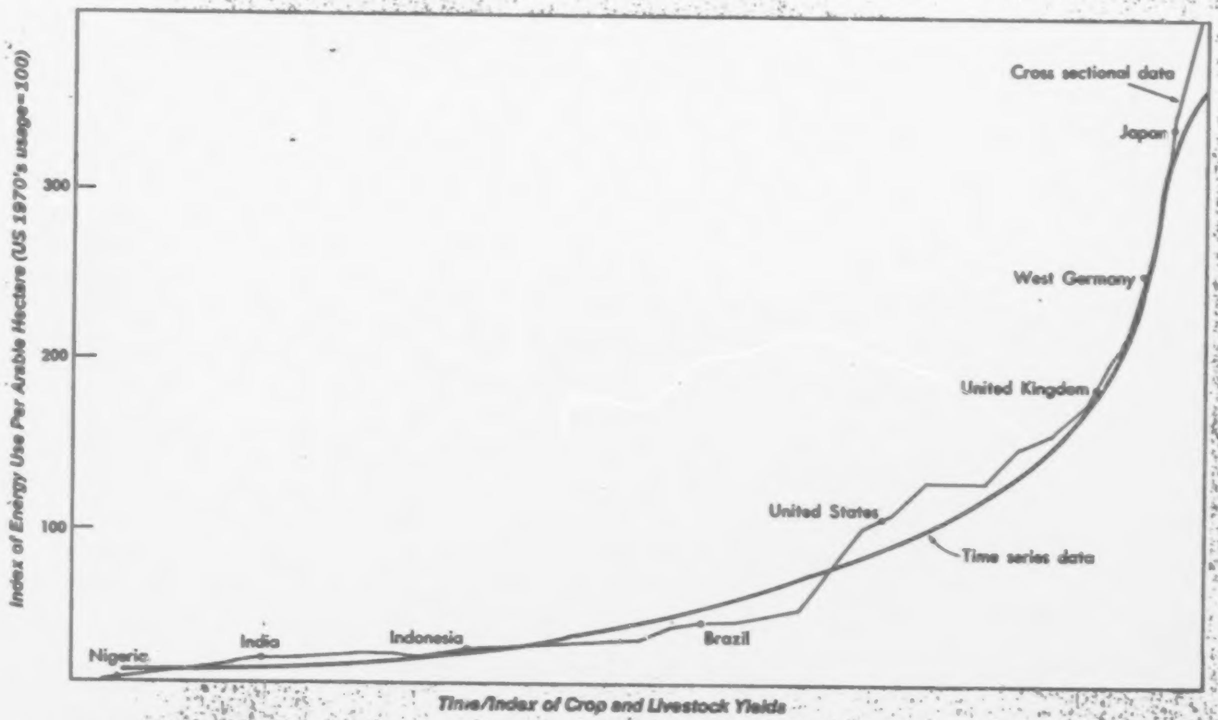


Figure 59. Energy intensity data. Cross-sectional energy use data plotted against crop and livestock yields for 30 largest food producing countries; 15-year historical series plotted against time for United States and several major European producers (455).

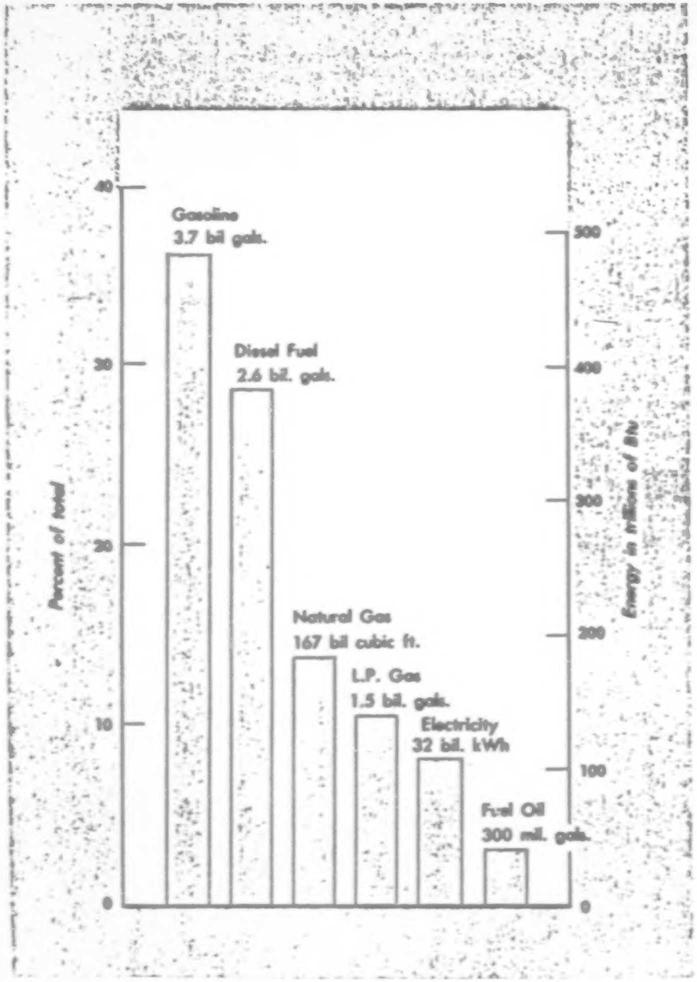


Figure 60. Energy used in agriculture, 1974 (455).

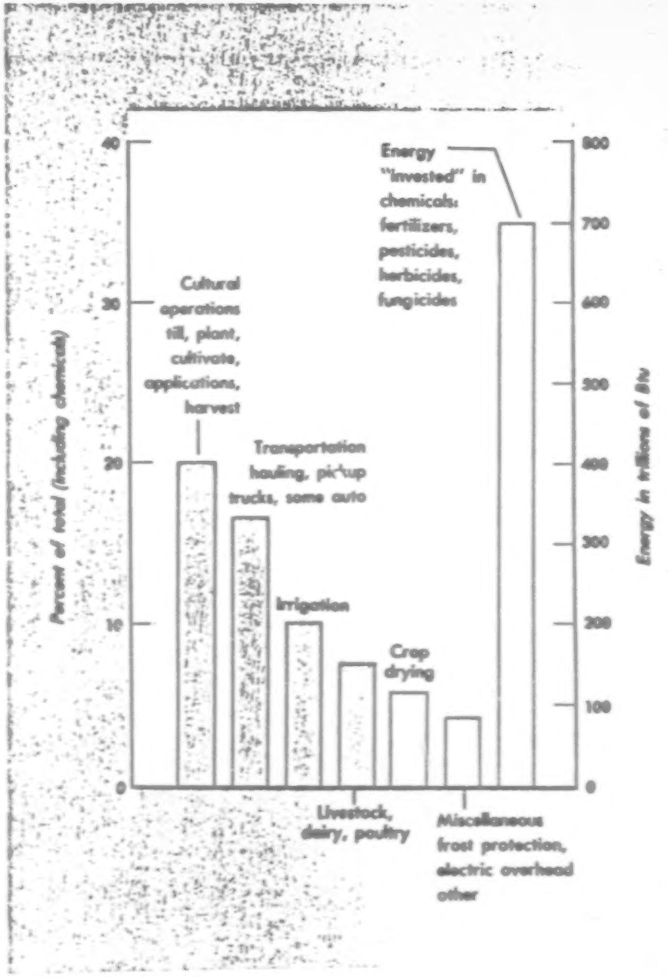


Figure 61. Energy used in agriculture, plus fertilizer and chemicals, 1974 (455).

food chain requires an input of 35.5 billion joules of cultural energy to produce 5 billion joules of 38% animal and 62% vegetable food products (Fig. 62), a ratio of 7.1:1. Other estimates are about 10:1.

Populations of cattle and of sheep and goats are extrapolated from growth rates between 1955 and 1976 to populations in the year 2000 (Table 32). However, resources are already limited and extensive overgrazing has occurred in many regions. The Winrock projections based on growth in feed supply (Table 33) are slightly greater for cattle and smaller for sheep and goats (Table 34).

6.2.3.2 Land Deterioration

Extensive overgrazing, deforestation, soil erosion, salinization and desertification have resulted from the ever-increasing pressure on the land to produce. As a result deserts are expected to increase about 62% by the year 2000. Annual production losses because of salinization and desertification were estimated to total \$15.6 billion of which \$3.3 billion was from the waterlogging and salinization of irrigated lands, \$6.7 billion was from range deterioration and \$5.6 billion was due to deterioration of rainfed cropland (455). Desertification, defined rather broadly, was widely distributed (Fig. 63). The production loss potential was 40% on irrigated land, 60% on rangeland and 25% on rainfed cropland. Average gross incomes per hectare from undeteriorated lands were estimated at \$400 per irrigated land, \$90 per rainfed cropland and \$3.50 for rangeland. Cost estimates to combat desertification are \$400 million per year. So far no global price tag has been placed on halting erosion or overgrazing.

The low production estimate for rangeland value may account for the almost total lack of mention of rangeland in the Global 2000 Report except for a very,

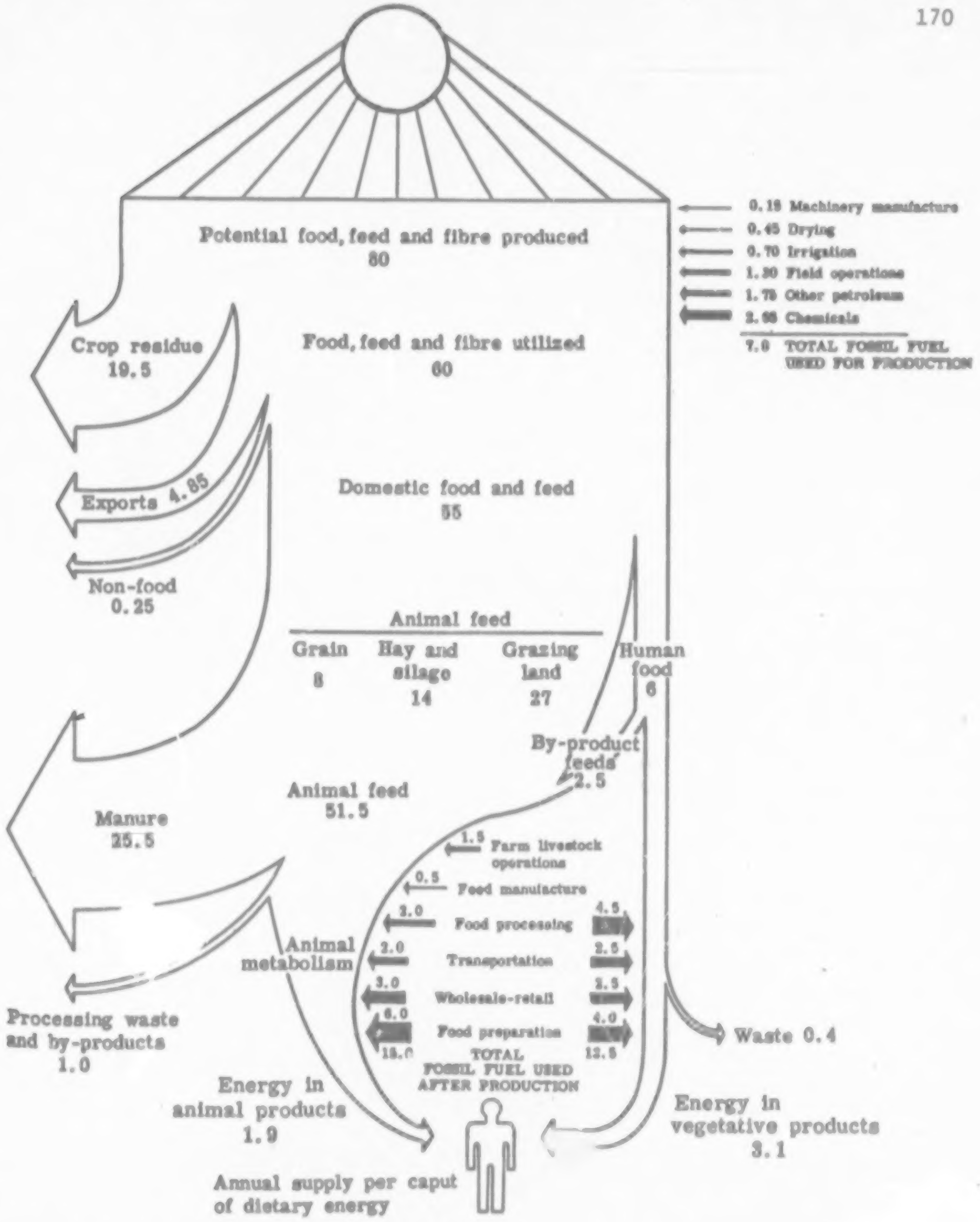

Potential food, feed and fibre produced
80
Food, feed and fibre utilized
60
Domestic food and feed
55
Crop residue
19.5
Exports 4.85
Non-food
0.25
0.18 Machinery manufacture
0.45 Drying
0.70 Irrigation
1.30 Field operations
1.75 Other petroleum
2.95 Chemicals
7.0 TOTAL FOSSIL FUEL USED FOR PRODUCTION
Animal feed
Grain
8
Hay and silage
14
Grazing land
27
Human food
6
By-product feeds
2.5
Manure
25.5
Animal feed
51.5
1.5
Farm livestock operations
0.5
Feed manufacture
2.0
Food processing
4.5
2.0
Transportation
2.5
3.0
Wholesale-retail
2.5
6.0
Food preparation
4.0
15.0
TOTAL FOSSIL FUEL USED AFTER PRODUCTION
13.5
Animal metabolism
Processing waste and by-products
1.0
Waste 0.4
Energy in animal products
1.9
Energy in vegetative products
3.1
Annual supply per caput of dietary energy

Figure 62. Energy flow in the U.S. food chain, in billions of joules. (Fr
The State of Food and Agriculture 1976, FAO, 1977; adapted from F. C. Stickler et al., Energy from Sun to Plant, to Man, Deere & Co., 1975) (455).

Table 32. Number of Cattle and Number of Sheep and Goats, 1955-2000 (455)

	Cattle				Sheep and goats			
	1955	Annual growth[1]	1976	2000[1]	1955	Annual growth[1]	1976	2000[1]
	(In millions of head)							
Developing market economies[2]								
Free	514.3	1.7	696.3	904.3	587.8	1.3	754.3	944.6
Centrally planned	57.5	1.2	71.6	87.7	101.6	2.5	154.8	215.6
Subtotal	571.8	1.6	767.9	992.0	689.4	1.5	909.1	1160.2
Developed market economies[2]								
Free	225.0	1.6	302.0	390.0	364.8	-0.1	359.6	353.7
Centrally planned	81.2	3.7	143.9	215.6	146.7	1.1	182.0	222.3
Subtotal	306.2	2.2	445.9	605.6	511.5	0.3	541.6	576.0
World total	878.0	1.8	1213.8	1597.6	1200.9	1.0	1450.7	1736.20

Source: The State of Food and Agriculture 1977, Rome: Food and Agriculture Organization, Nov. 1977, Ch. 3, pp. 3-16 (draft).

[1] Both the annual growth and the projection to 2000 are based on a linear rather than compound (i.e., exponential) growth model. Reviewers of the manuscript felt that, in view of range conditions, an exponential growth model gave unrealistically large animal populations in 2000.

[2] Including countries in regions not specified.

Table 33. Winrock Projections of World Feed Resources for Ruminants (455)

Feed	Supply (billions of Mcal) 1970	2000	% of Total	Projected change, %
Permanent pastures and meadows	4,820	5,610	37.9	+16.4
Arable lands forage	3,115	3,775	25.5	+21.2
Nonagricultural lands forage	1,019	719	4.8	-29.4
Grain	439	767	5.2	+74.7
Agri-industry by-products	128	215	1.4	+68.0
Oilseeds	83	164	1.1	+97.6
Crop residues	2,945	3,560	24.0	+20.9
World total	12,549	14,810		+18.0

Table 34. Winrock Projections of World Ruminant Populations (455)

Ruminant	Population, millions 1972	2000	Increase, %
Cattle	1,130	1,435	27
Buffalo	127	169	29
Sheep and goats	1,435	2,005	40
Camels	—	24,311	—

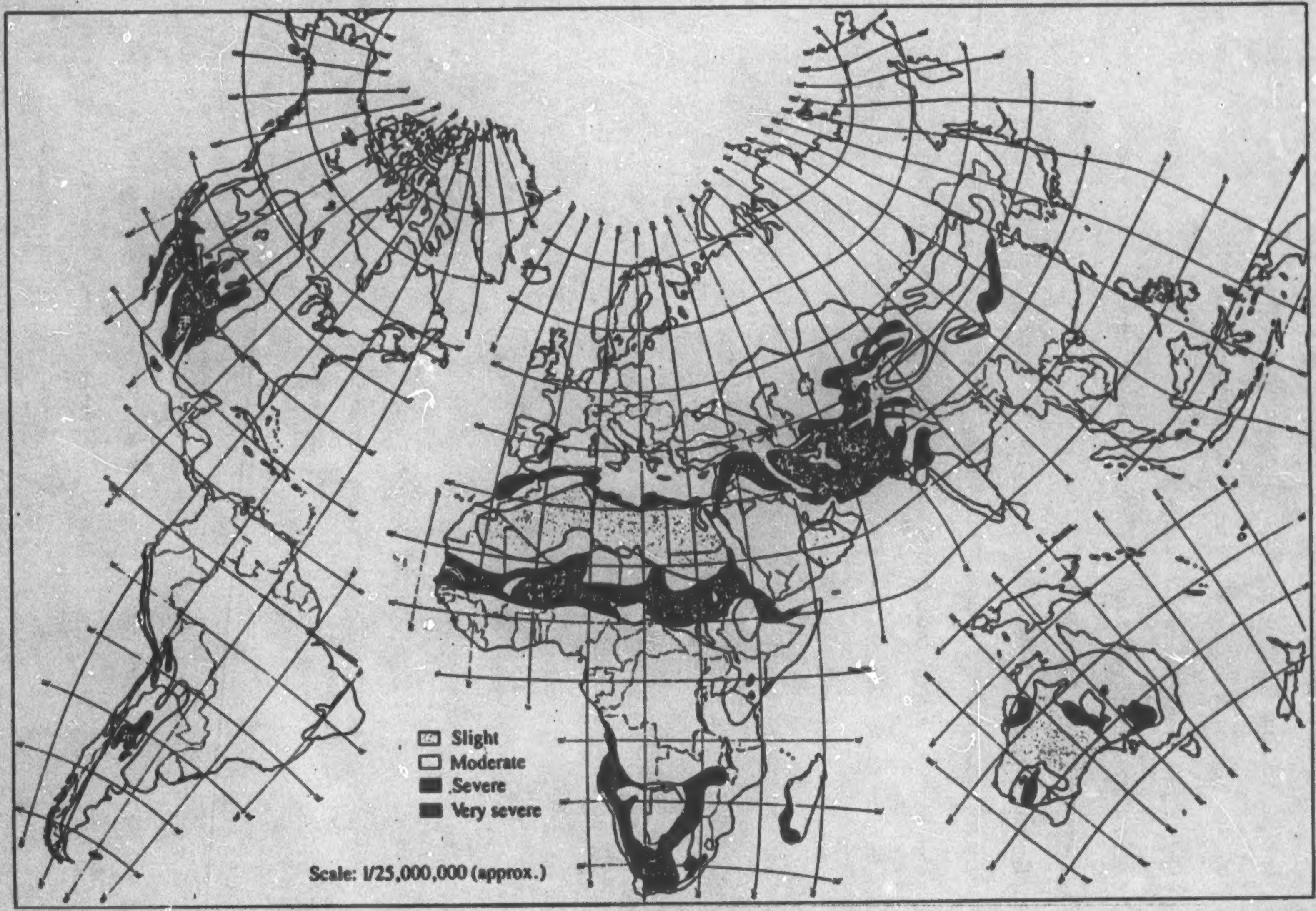

▨ Slight
☐ Moderate
■ Severe
■ Very severe
Scale: 1/25,000,000 (approx.)

Figure 63. Desertification Map (U.N. Desertification Conference, 1977, 455).

very few references in the context of overgrazing and desertification. Some rangeland is included in open woodland, some (but not all) of the scrub and brushland is included in total forest land, but not in either closed forest or open woodland. When the land categories listed in Chapter 8 "Forestry" are subtracted from the total land area, there is an unnamed remainder of about 71 million square kilometers or 48% of the land surface. This land is almost entirely range and has been almost completely ignored in the Global 2000 Report. In contrast, Bommer (457) summarizes United Nations reports showing that rangeland supplies 90% of the nutrition for ruminants in the Near East and the Sudan, 88% in Ethiopia, 81% in Greece and 73% in Uruguay. Many of these lands are severely overgrazed.

Deforestation of the tropical rain forest poses a special danger. The closed forests are expected to decrease 17% by the year 2000.

6.2.3.3 Exhaustion of Resources

Not only are the agricultural resources being depleted, but the life expectancy of world reserves of 17 critical minerals is less than a century at expected rates of usage (Table 35), five of them less than 25 years. While oil prices are being manipulated by political as well as economic considerations, if oil demand grows at 5% per year, demand is expected to exceed production in the 80s, at 3% per year in the 90s and at 2% per year by the year 2000 (Fig. 64).

6.2.3.4 Pollution

A very large amount of pollutants are being released annually on land, into the oceans and into the air. A very large amount of various kinds of particulate matter are released into the air by natural processes each year,

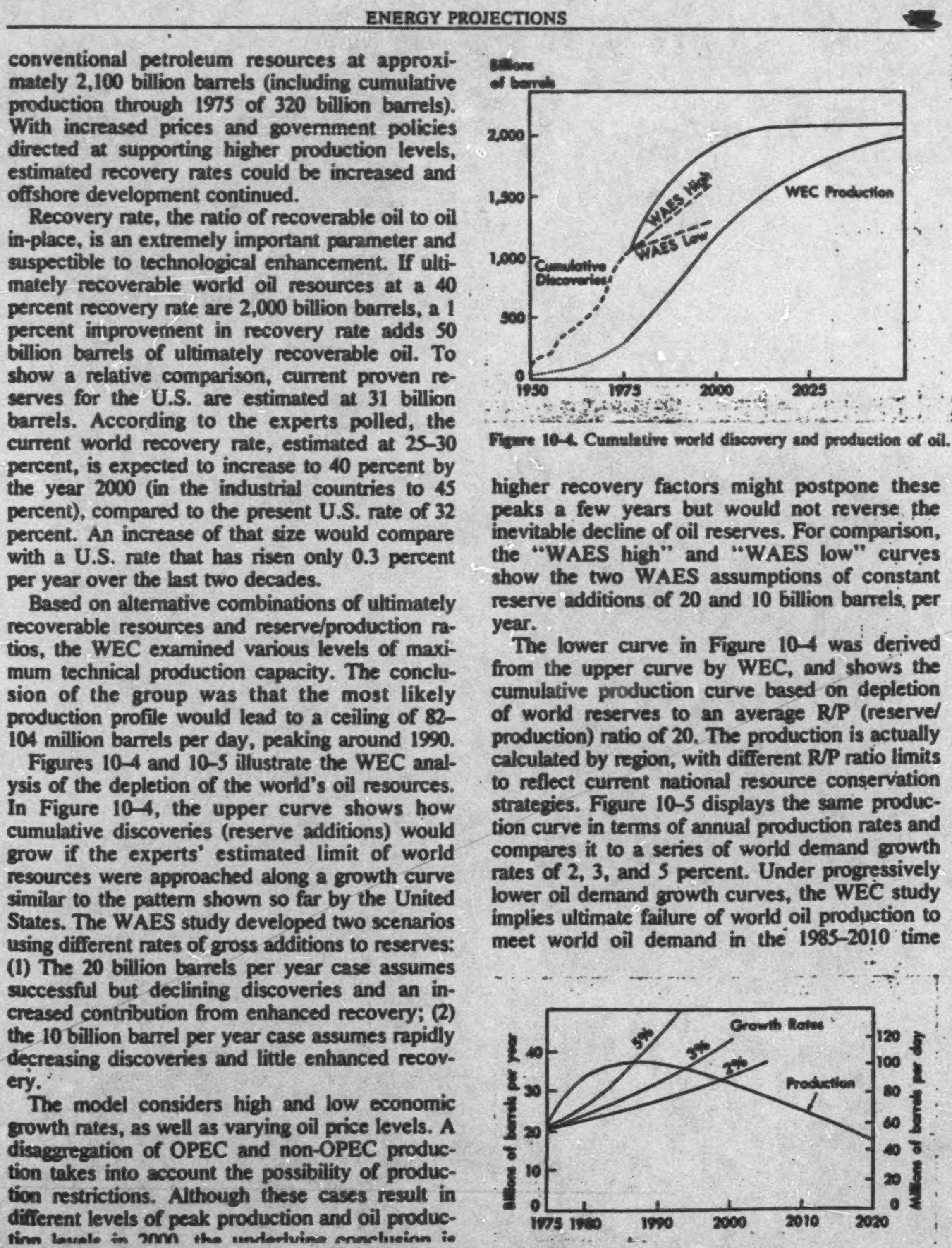
Table 35. Life Expectancies of 1976 World Reserves of Selected Mineral Commodities at Two Different Rates of Demand (455)

	1976 Reserves	1976 Primary demand	Projected demand growth rate, %	Life expectancy in years[1] Static at 1976 level	Life expectancy in years[1] Growing at projected rates
Florine (million short tons)	37	2.1	4.58	18	13
Silver (million troy ounces)	6,100	305	2.33	20	17
Zinc (million short tons)	166	6.4	3.05	26	19
Mercury (thousand flasks)	5,210	239	0.50	22	21
Sulfur (million long tons)	1,700	50	3.16	34	23
Lead (million short tons)	136	3.7	3.14	37	25
Tungsten (million pounds)	4,200	81	3.26	52	31
Tin (thousand metric tons)	10,000	241	2.05	41	31
Copper (million short tons)	503	8.0	2.94	63	36
Nickel (million short tons)	60	0.7	2.94	86	43
Platinum (million troy ounces)	297	2.7	3.75	110	44
Phosphate rock (million metric tons)	25,732	107	5.17	240	51
Manganese (million short tons)	1,800	11.0	3.36	164	56
Iron in ore (billion short tons)	103	0.6	2.95	172	62
Aliminum in bauxite (million short tons)	5,610	18	4.29	312	63
Chromium (million short tons)	829	2.2	3.27	377	80
Potash (million short tons)	12,230	26	3.27	470	86

Note: Corresponding data for helium and industrial diamonds not available.

[1] Assumes no increase to 1976 reserves.

Source: After Global 2000 Technical Report, Table 12-4, but with updated and corrected entries. Updated reserves and demand data from U.S. Bureau of Mines, Mineral Trends and Forecasts, 1979. Projected demand growth rates are from Global 2000 Technical Report, Table 12-2.



conventional petroleum resources at approximately 2,100 billion barrels (including cumulative production through 1975 of 320 billion barrels). With increased prices and government policies directed at supporting higher production levels, estimated recovery rates could be increased and offshore development continued.

Recovery rate, the ratio of recoverable oil to oil in-place, is an extremely important parameter and suspectible to technological enhancement. If ultimately recoverable world oil resources at a 40 percent recovery rate are 2,000 billion barrels, a 1 percent improvement in recovery rate adds 50 billion barrels of ultimately recoverable oil. To show a relative comparison, current proven reserves for the U.S. are estimated at 31 billion barrels. According to the experts polled, the current world recovery rate, estimated at 25–30 percent, is expected to increase to 40 percent by the year 2000 (in the industrial countries to 45 percent), compared to the present U.S. rate of 32 percent. An increase of that size would compare with a U.S. rate that has risen only 0.3 percent per year over the last two decades.

Based on alternative combinations of ultimately recoverable resources and reserve/production ratios, the WEC examined various levels of maximum technical production capacity. The conclusion of the group was that the most likely production profile would lead to a ceiling of 82–104 million barrels per day, peaking around 1990.

Figures 10–4 and 10–5 illustrate the WEC analysis of the depletion of the world's oil resources. In Figure 10–4, the upper curve shows how cumulative discoveries (reserve additions) would grow if the experts' estimated limit of world resources were approached along a growth curve similar to the pattern shown so far by the United States. The WAES study developed two scenarios using different rates of gross additions to reserves: (1) The 20 billion barrels per year case assumes successful but declining discoveries and an increased contribution from enhanced recovery; (2) the 10 billion barrel per year case assumes rapidly decreasing discoveries and little enhanced recovery.

The model considers high and low economic growth rates, as well as varying oil price levels. A disaggregation of OPEC and non-OPEC production takes into account the possibility of production restrictions. Although these cases result in different levels of peak production and oil production levels in 2000, the underlying conclusion is

Figure 10-4. Cumulative world discovery and production of oil.

higher recovery factors might postpone these peaks a few years but would not reverse the inevitable decline of oil reserves. For comparison, the "WAES high" and "WAES low" curves show the two WAES assumptions of constant reserve additions of 20 and 10 billion barrels per year.

The lower curve in Figure 10–4 was derived from the upper curve by WEC, and shows the cumulative production curve based on depletion of world reserves to an average R/P (reserve/production) ratio of 20. The production is actually calculated by region, with different R/P ratio limits to reflect current national resource conservation strategies. Figure 10–5 displays the same production curve in terms of annual production rates and compares it to a series of world demand growth rates of 2, 3, and 5 percent. Under progressively lower oil demand growth curves, the WEC study implies ultimate failure of world oil production to meet world oil demand in the 1985–2010 time

Figure 64. World maximum oil production at a medium depletion rate and world demand at three growth rates for oil production (455).

including sea salt, soil dust, volcanic particles, ash and smoke from forest fires, and various particles formed from gasses, including sulfates, nitrates, ammonium ions, and organic aerosols. Man's activities are thought to be contributing about 15% as much particulate matter to the atmosphere as natural sources, although data are not precise. Burning and accelerated wind erosion, which are major sources, were not considered. Both gaseous and particulate matter emissions are increasing rapidly, especially in the industrialized nations.

Carbon dioxide emissions are a major concern. Carbon dioxide concentration in the atmosphere in Hawaii have increased 6% from 1958-78 (Fig. 65). Expected CO_2 concentrations resulting from five different scenarios of energy show possibly dramatic increases shortly after 2000 (Fig. 66).

6.2.3.5 Possible Climatic Changes

The increase of particulate matter predisposes to global cooling and increase of CO_2 concentration to global warming as discussed in section 2. Both perterbations change the vertical temperature gradient. The relative importance of CO_2 concentration and atmospheric turbidity due to particulate matter in five different climatic scenarios are shown in Table 36 along with the probability of different incidences of drought during the 90s in different regions of the world. The most probable scenario for the near future is for the weather to remain similar to the last 30 years, although this is less likely in a longer time frame. Global warming or cooling appears equally probable. Note that regardless of the scenario there is a high probability in the U. S. of a series of drought years during the 90s similar to that of the early 30s and early 50s. The forces predisposing to the occurrence of drought in the Great Plains at 20-22 year intervals, associated with the double sunspot

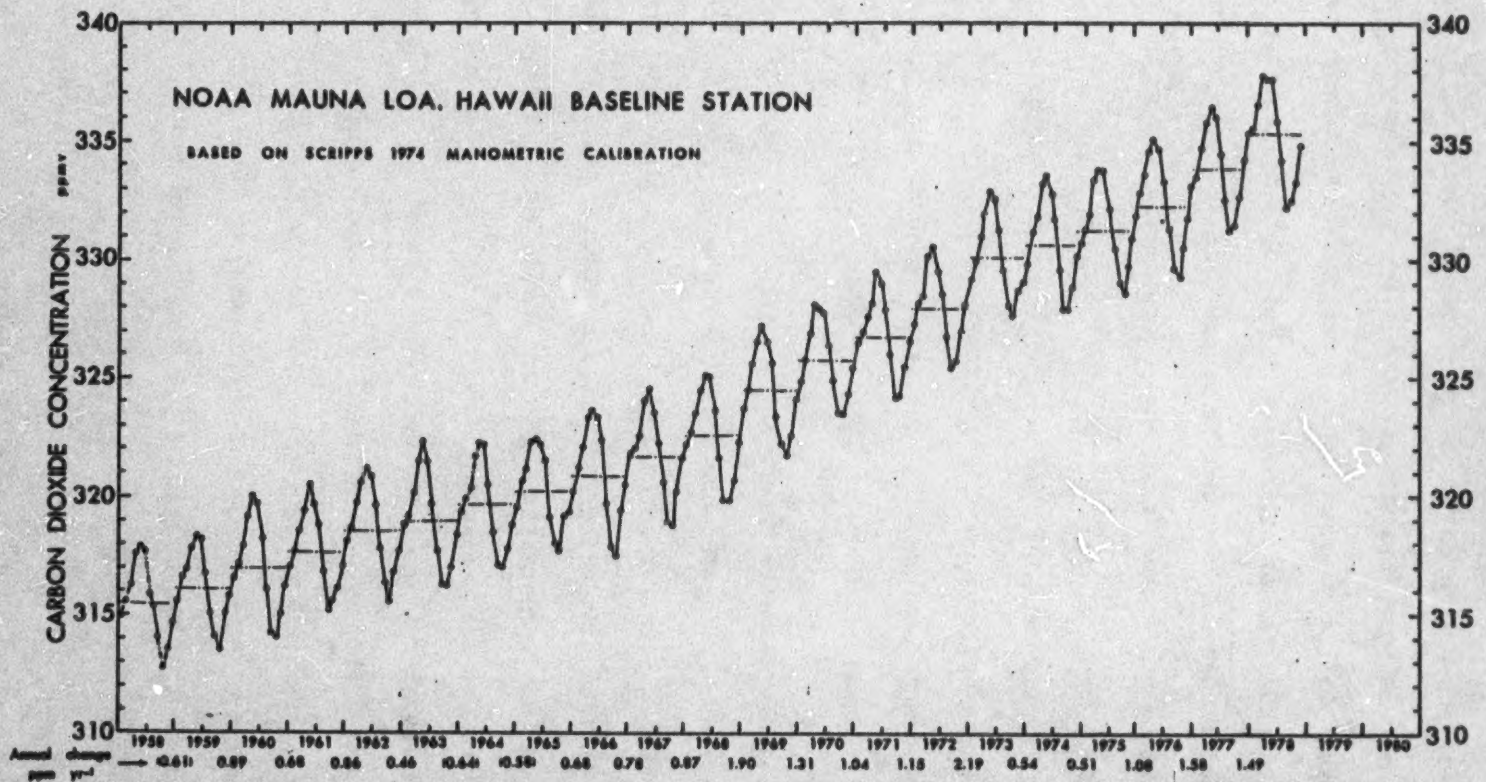


Figure 65. Trend since 1958 in the concentration of carbon dioxide in the atmosphere (parts per million by volume), as monitored at the National Oceanic and Atmospheric Administration's Mauna Loa Observatory, Hawaii, 19.5° N latitude, 3,401 meters altitude. (L. Machta, NOAA Air Resources Laboratories, 1979, 455).

262 THE PROJECTIONS

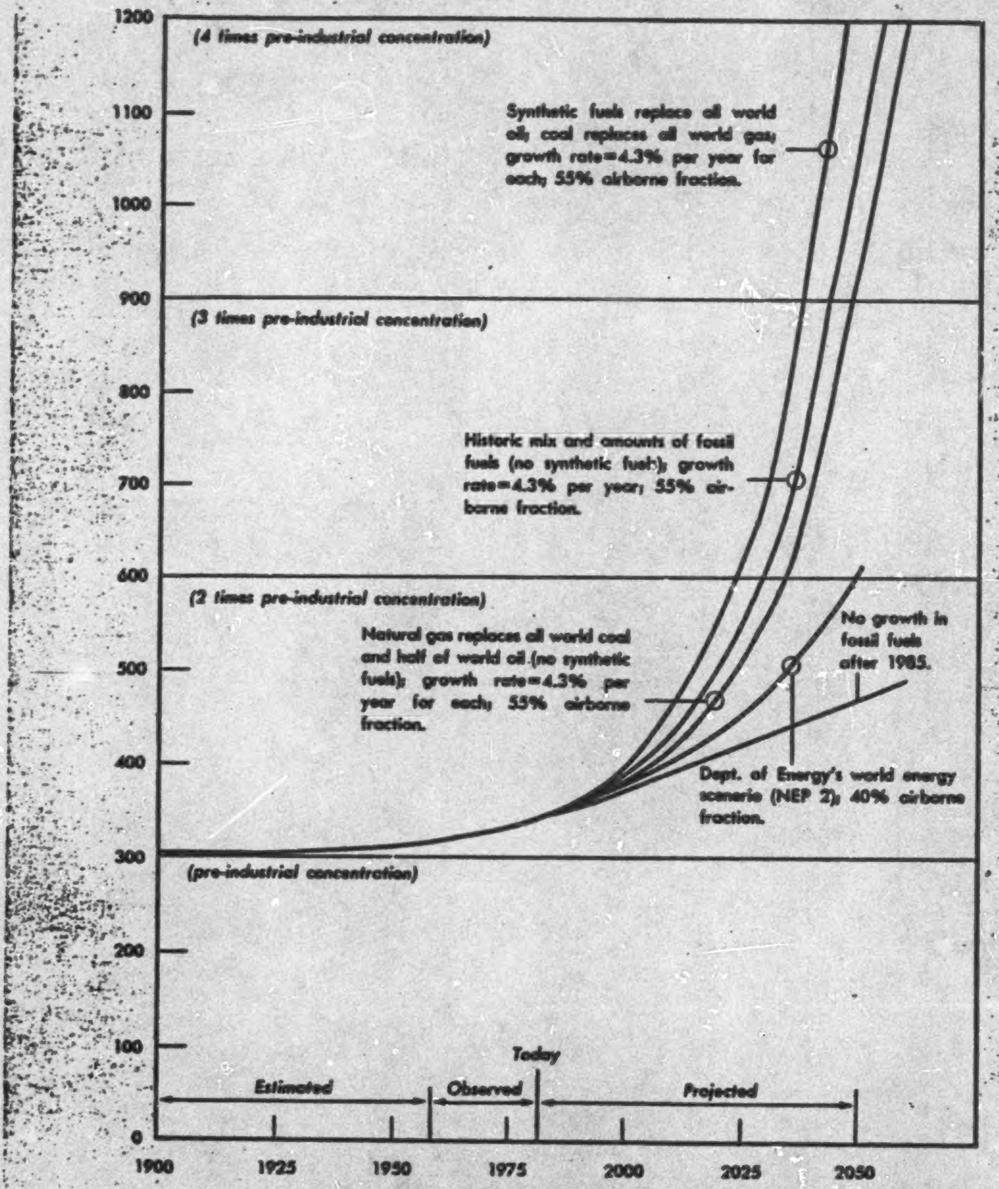


Figure 66. Carbon dioxide concentrations implied by various energy scenarios. Synthetic fuels derived from coal are assumed to release 3.4 x 10^{15} grams of carbon in CO_2 per 100 quads of energy. Airborne fraction is the percent of emitted CO_2 that remains in the atmosphere. (U.S. Department of Energy, 455).

Table 36. Five Global Scenarios of Future Climates with Estimates of Their Probability and the Probability of Three Precipitation Patterns in Various Areas of the World in the 1990s (455)

		Global scenario					
		Cooling		Same as last 30 years	Warming		Weighted mean
		Large	Moderate		Moderate	Large	
Probability of scenario		.1	.25	.30	.25	.10	
Relative importance							
CO$_2$		15	20	50	60	90	—
Turbidity		85	80	50	40	10	—
Probability of drought in 1990s							
U.S.	Frequent	.7	.6	.5	.5	.7	.6
	Average	.2	.3	.4	.3	.2	.3
	Infrequent	.1	.1	.1	.2	.1	.1
Other mid-latitudes	Frequent	.7	.5	.4	—	.3	—
	Average	.2	.4	.5	—	.3	—
	Infrequent	.1	.1	.1	—	.4	—
Sahel	Frequent	.6	.5	.2	.3	.1	.3
	Average	.3	.4	.7	.4	.6	.5
	Infrequent	.1	.1	.1	.3	.3	.2
Monsoon lands							
NW India	Frequent	.5	.4	.2	.2	.0	.3
	Average	.5	.6	.5	.5	.2	.5
	Infrequent	.0	.0	.3	.3	.8	.2
Other India	Frequent	.6	.5	.2	—	.1	—
	Average	.3	.4	.5	—	.2	—
	Infrequent	.1	.1	.3	—	.7	—
Other Asia	Frequent	.5	.4	.2	—	.1	—
	Average	.4	.5	.6	—	.2	—
	Infrequent	.1	.1	.2	—	.7	—
Mean of all	Frequent	.6	.5	.3	—	.2	—
	Average	.3	.4	.5	—	.3	—
	Infrequent	.1	.1	.2	—	.5	—

cycle, appear to be operative regardless of the levels of CO_2 or particulate matter. Widespread drought would be made more probable by large global cooling. More favorable precipitation periods would be more probable, especially in the Monsoon Lands with global warming. Under all scenarios, drought will continue to be a problem. In the future serious prolonged drought anywhere in the world is likely to produce famine.

6.2.3.6 Growth of Technology

The challenge of problems on a global basis is contributing to the growth of technology in an attempt to solve or ameliorate the problems. Yet, the misapplication of technology will create far more problems than it will cure.

6.2.3.7 Summary Statement

Governmental regulation, in the U. S. as well as the world, will increase in reaction to the problems described above. There will continue to be pressure for world planning to solve world problems and for redistribution of income on a world as well as a national basis.

World-wide inflation, related to the scarcity or deterioration of resources and their manipulation; wages and benefits increasing faster than productivity; inefficiencies due to lack of capital, lack of knowledge from good research, lack of incentives, and governmental regulation; the dissipation of resources for non-productive purposes, such as war; and poor financial and monetary policies; as well as other factors, is likely to continue. Because of the problem of inflation and the scarcity of capital, high interest rates are likely to remain. Land managers will be under continual pressure to try to produce more than the land can produce on a sustained basis, thus predisposing to deterioration.

While all prices will probably remain high, commodities with high cultural energy inputs, scarce commodities and food probably will be priced relatively higher than other items. The occurrence of any type of disruption to the normal functioning of the food-producing and distribution system, whether it be drought, flood, snow, blizzard, disease, political unrest or war, could trigger widespread famine, especially as population increases.

War (especially nuclear war with attendant radiation contamination), breakdown of fiscal and monetary policies, severe depression, widespread famine or disease, as well as other catastrophes, could drastically change these expectations for the future. Likewise, one or more scientific breakthroughs, such as success in modifying the photosynthetic process to produce food outside the cell or to produce fuel directly, could change a gloomy picture into one of hope.

6.3 Financial Status and Problems of Ranches on the Great Plains

The ranch has been described and diagrammed as an ecosystem (Fig. 67, 307) with numerous connections with national and world ecosystems and with three subsystems (land, livestock and management). Management considerations for each of these subsystems are summarized briefly in Tables 37, 38, and 39. The importance of decision-making with complete flexibility in the light of knowledge that is as complete as possible cannot be over-emphasized. Typically the management of Great Plains ranches is greatly restricted by tradition, lack of knowledge, and economic constraints.

Global and national trends described in the previous section are creating real financial problems for Great Plains ranchers. Some efficiency measures of typical cow-calf ranches, expressed on an animal unit basis are shown in

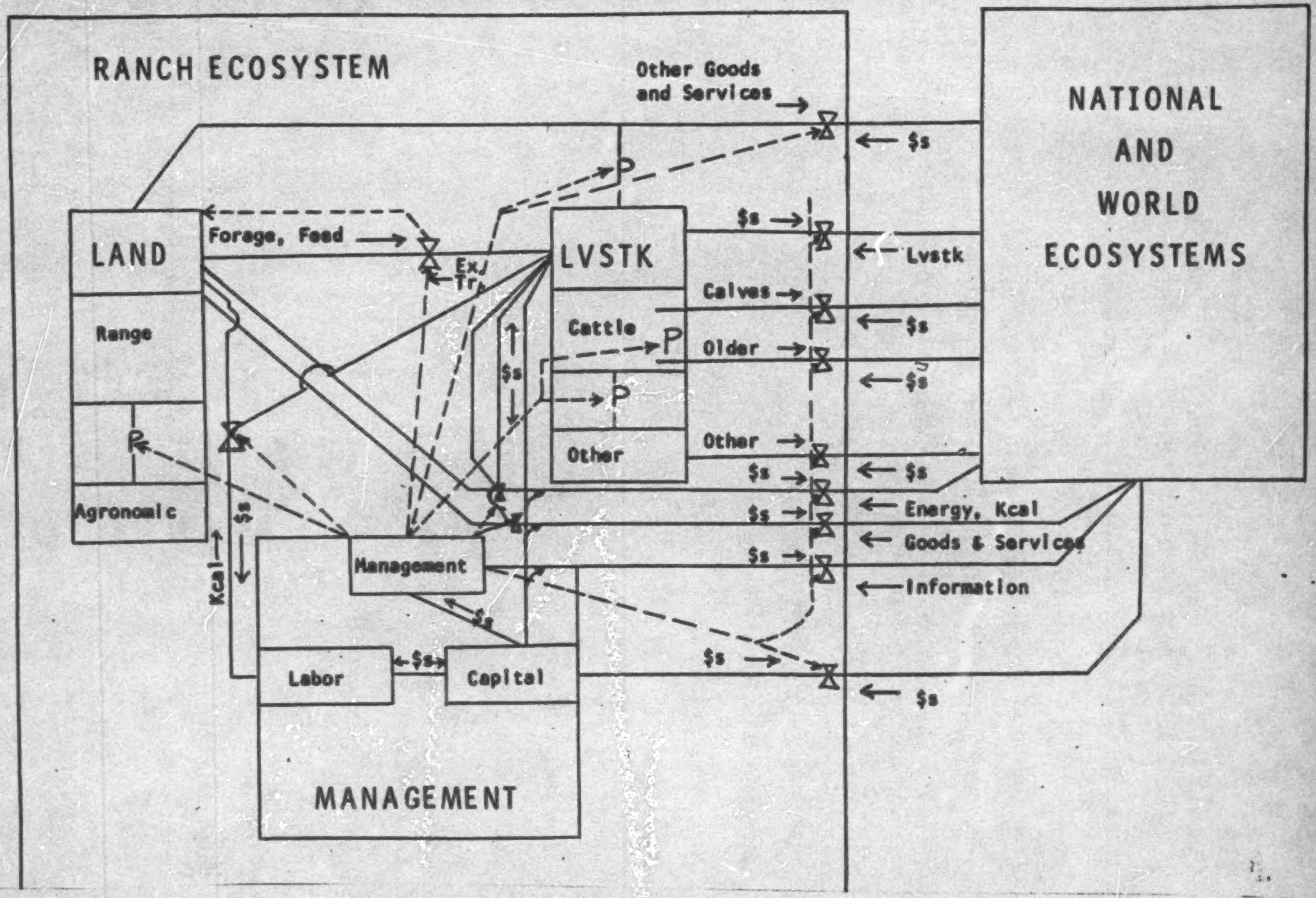

RANCH ECOSYSTEM
NATIONAL AND WORLD ECOSYSTEMS
Other Goods and Services
$s
LAND
Range
P
Agronomic
Forage, Feed
Ex/Tr
LVSTK
Cattle
P
P
Other
$s
Lvstk
Calves
Older
Other
Energy, Kcal
Goods & Services
Information
Kcal
Management
Labor
Capital
MANAGEMENT

Figure 67. Flow chart for a ranch ecosystem showing the relationship with national and world ecosystems and the relationships of the land, livestock and management subsystems within the range ecosystem. Solid lines show flows of materials; dotted lines are management decisions that control flows or proportions (P) of resources allocated to different uses (307).

Table 37. Management Considerations for the Land Subsystem of the Ranch Ecosystem with Special Reference to Range (modified from 307)

Optimize

1. Combination of products
2. Proportion of range, introduced pasture and crop
3. Ecosystem structure to produce the desired combination of products--with special consideration for
   - Adaptation to site constants and driving variables
   - Potential forage production
   - Nutritional value of forage
   - Response to management inputs
   - Prey-predator relationships
4. Limiting factors
5. Competing herbivory
6. Utilization methods with special consideration for
   - Proportion of feeding and grazing
   - Kind and proportion of grazing animals
   - Grazing distribution
   - Season of grazing
   - Grazing system
   - Stocking rate

Table 38. Management Considerations for the Livestock Subsystem for the Ranch Ecosystem (modified from 307)

Optimize

1. Production system
2. Genetic potential

   Considering

      Adaptation to site constants and driving variables

      Product quality

      Lifetime production efficiency

   Using

      Selection

      Mating systems

      Genetic engineering

   Augmented by

      Natural breeding

      Artificial insemination

      Ova transfer

3. Nutritional plane

   For

      Product quality

      Lifetime production efficiency

   Using

      Grazing management

      Supplemental feeding

      Emergency and drylot feeding

Table 38. Continued

Optimize

4. Metabolic regulation
5. Disease and parasite levels
6. Animal comfort and safety
7. Marketing practices

Table 39. Management Considerations for the Management Subsystem of the Ranch Ecosystem (modified from 307)

---

1. Development of goals and objectives
2. Inventory, analysis and problem definition in a world context
    a. Information flow to management from (and from management to)
        All subsystems of the ranch ecosystem (complete computerized ranch records)
        Product processors and consumers
        Suppliers of products and services
        Agencies and individuals studying
            Ranch ecosystems
            National and world ecosystems
        Local, state, national and world governments
    b. Evaluation and problem definition in relation to goals
3. Development and documentation of alternatives to solve the problems and meet the management objectives
4. Selection of the optimum alternatives using
    Statistical models
    Simulation models
    Optimization models
    Judgment
5. Implementation of the Plan in harmony with capital constraints
6. Evaluation of the Plan with reference to goals, biologic and economic efficiency
7. Revision, implementation and reevaluation

Table 40 from Gray (450). Trends in net ranch income (income due to land capital, non-land capital, labor and management) of medium-sized ranches in the Plains area of northeastern New Mexico for 13 years (1965-77) as related to cattle prices and precipitation (Table 41 from Gray, 448) show large yearly fluctuations with large negative values after 1973. Gray commented, "Significantly, prices in 1977 were higher than in 1970 and 1971, while the index of precipitation was higher in 1971 and lower in 1970. One would expect net incomes to be about the same in these two time periods. Actually net incomes were about $8,200 in 1970-71 and a loss of about the same amount in 1977. The change demonstrates the impact of the cost-price squeeze which has been particularly serious on ranches since 1973." Increased costs of specific rangeland facilities are shown in Table 42. Furthermore, numbers of these items were increased in an attempt to improve efficiency.

In general the cost-price squeeze is related to the purchasing power of the dollar, which like the German mark and the British pound, declined precipitously after the beginning of World War II, declined more slowly from 1951 through 1972 and rapidly since 1973 (Fig. 68, 451). More specifically, increased petroleum prices directly affected many ranch costs. In 1977, the small ranches were much worse off than the larger ones both in losses in net ranch income and in debt as a percentage of assets (Table 43, 448).

Drought has occurred sporadically through the 70s with especially severe drought in the northern Plains in 1973, 1976, and 1980. Personal conversations with several South Dakota bankers indicate much higher debt loads than shown in Table 43. Gray calculated that the break-even price for weaning calves to pay all operating costs, capital costs and a return to labor and management was $1.40 per pound when the actual price was 39¢. In other words, "From one

Table 40. Efficiency Measures of Typical Cow-calf Ranches, Selected Areas of the Great Plains[1] (450)

Ranch location	Efficiency measures per animal unit						
	Total investment	Annual beef sales	Gross income	Cash cost	Non-cash cost	Total cost	Net ranch income
	dollars	pounds	- - - - - - - - - - -	- - - - - -	dollars - -	- - - - - -	- - - - - -
			Small ranches (80-148 animal units)				
Colorado Plains	933	479	176	70	18	88	88
Montana Northern Great Plains	800	341	92	42	22	64	28
New Mexico Northeast	1,550	308	83	42	10	52	31
Texas High Plains (SW)	1,806	340	74	35	18	53	21
			Medium ranches (215-331 animal units)				
Colorado Plains	912	298	67	44	11	55	12
Montana Northern Great Plains	704	348	84	36	18	54	30
New Mexico Northeast	1,300	317	63	35	6	41	22
Texas High Plains (SW)	1,753	314	66	34	10	44	22
			Large ranches (479-578 animal units)				
Colorado Plains	1,071	312	80	41	9	50	30
Montana Northern Great Plains	734	351	84	42	17	59	25
New Mexico Northeast	1,581	322	64	34	6	40	24
Texas High Plains (SW)	1,885	314	67	24	9	33	34

---

[1] Gray, James R., Organization, Costs, and Income of Western Cattle and Sheep Ranches, New Mexico Agr. Exp. Sta. Bul. 587, Oct. 1971.

Table 41. Net Ranch Income of Medium-sized Ranches in the Plains Area of Northeastern New Mexico as Related to Cattle Prices and Precipitation (448)

Year	Steer calf price per cwt.	Index of annual precipitation	Net income per ranch
1965	$23.56	100	$ 6,510
1966	27.09	74	3,770
1967	27.09	84	6,240
1968	28.98	62	3,175
1969	32.38	123	8,880
1970	34.16	61	8,785
1971	37.93	89	7,610
1972	44.76	107	18,070
1973	57.25	77	20,215
1974	31.81	76	-2,130
1975	28.03	65	-7,140
1976	33.20	76	-8,250
1977	39.44	77	-8,460

Table 42. Changes in Number and Cost of Rangeland Facilities from 1965-1977 in Northeastern New Mexico on Medium-sized Cow-calf Ranches (448)

Facility	Unit	Cost per unit, % change	Numbers per ranch, % change
Corrals	ea	+200	0
Wells	ea	+182	+33
Pipelines, plastic	mi	+233	+700
Tanks	ea	+353	+367
Fences	mi	+159	+17

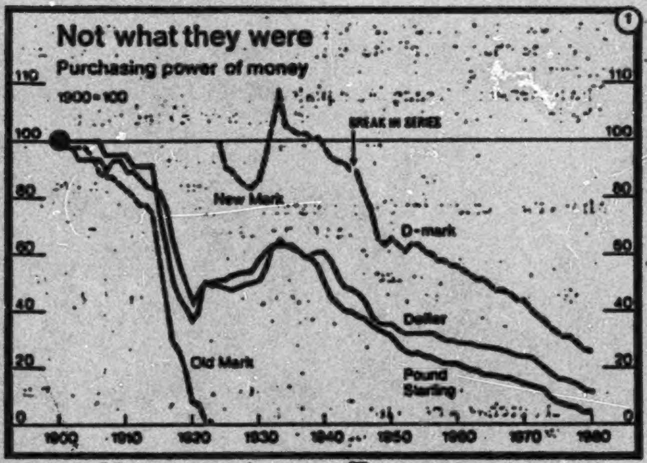


Figure 68. The purchasing power of money (451).

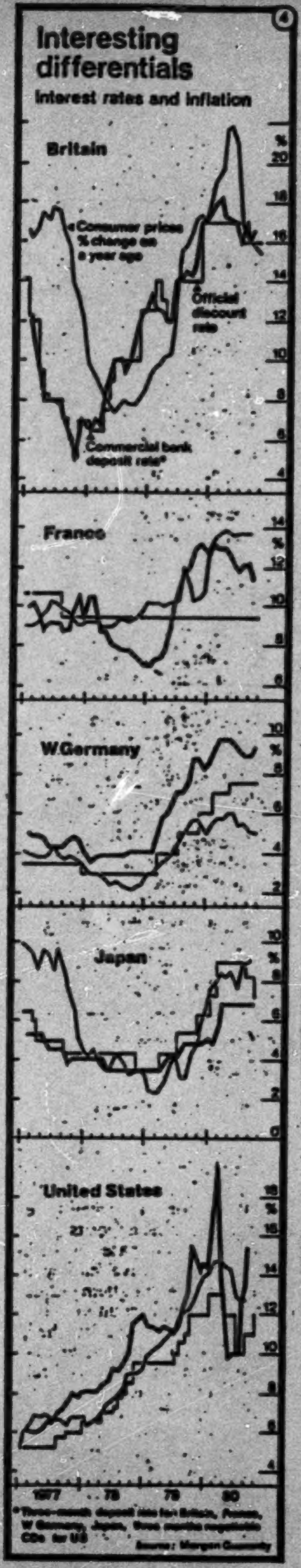


Figure 69. Interest rates and inflation (451).

Table 43. Financial Summary of Great Plains Ranches in Northeastern New Mexico by Size, 1977 (448)

	Ranch size		
	Small	Medium	Large
Animal units per ranch	68	240	500
Investment per A.U., $	5020	4070	4630
Investment in facilities, % of total	6	8	5
Debt as % assets	21	10	11
Receipts per A.U., $	117	107	104
Costs per A.U., $	205	142	114
Net ranch income per A.U., $	-88	-35	-10

viewpoint, the range livestock industry should take credit for subsidizing the American consumer by about $1.00 per pound of cattle marketed" (448). Burch (1980, 436) comments as follows: "The rancher like the farmer is squeezed in peculiar ways by our political economy. The large scale corporations are found in only a few specialty areas--feedlots, vegetable and fruit growing processing operations. The high capital and land costs, the unpredictable variations of weather and nature and the returns of 3-4% on investment are seldom attractive to large corporations. They dominate at both ends of production--they supply the equipment, fertilizers and so forth, and they control the processing and distribution." "The feedlot is the only element in the meat production process that matches the images of the factory."

Furthermore, ranchers have steadily been losing political influence since the "one man--one vote" decision of the Supreme Court more than 25 years ago. Ranchers make up for less than 1% of the population. Essentially no Congressmen and certainly no Senators are elected from a constituency in which ranchers are a majority.

Since early in 1978, interest rates have fluctuated wildly, but always above 10%, even reaching 20% (Fig. 69, 451), and appear likely to remain high. High interest rates add drastically to the annual costs of production, both directly and indirectly. The capital for needed range improvement practices becomes expensive, if not impossible to obtain. Furthermore, the present value of future net returns from those practices which show slow response is very, very low.

Great Plains ranchers have been hit hard by the cost-price squeeze, drought, and high interest rates. Increased efficiency of production has kept some ranchers in business. In addition, some, especially small operators with land mortgages, have survived by virtue of disaster programs and further credit at high interest rates, even though they have increased efficiency.

In spite of low or negative returns on investment in rangeland, the price trend has continued upward. Price increases may be less than inflation in some areas during the last few years. Some South Dakota rangeland has sold at three times or more the productive value of the land, even when capitalized at the interest rates of a few years ago. The high land prices are probably due to the fact that relatively little land is being sold and demand exceeds the supply. Ranchers who sell their land at inflated prices for more intensive uses, such as urban expansion or uranium mining, can out-price local ranchers for the land. Ranchers who bought land at lower prices and have paid for it can afford to enlarge their operations and spread the inflated cost of the new land over the entire operation. Some land is purchased for speculation, especially to convert it to cropland. Some is purchased for special considerations, such as tax deductions. A young man with minimum resources trying to get started in the ranching business cannot buy rangeland with any reasonable expectation of paying for it from the proceeds of the ranch. For example, with a stocking rate of 0.4 AUMs per acre, a purchase price of $125 per acre, $500 per animal unit, grazing season of 10 months, hay feeding for 2 months, 17% replacement rate, 95% calf crop, 500 lb calves at weaning, and 10% interest rate, calves would have to sell for 92¢ per lb just to pay the interest on the investment on the land and the cattle, not including costs of production, taxes, depreciation or interest on investment in equipment or facilities or range improvement practices or return to labor and management. With inflation in land resulting in increased equity ranchers, facing drought and the cost-price squeeze have increased their debt load by borrowing on their equity in the land for operating capital. Continued high interest rates, drought, low livestock prices, and high costs could result in foreclosure on mortgages, putting more land on the market and bringing prices down more nearly to productive value.

Faced with the economic pressures described in this section, most of the ranchers will have great difficulty obtaining sufficient capital to invest in range improvement practices. Furthermore, the temptation will be very great when market prices drop to increase the stocking rate to try to keep income up; when market prices are up or in wet years to stock with more animals to catch up and reduce indebtedness; or in dry years to keep the stocking rate at a wet year level to try to keep the income level high enough to keep from having to borrow more money. Some old, established ranchers with excellent management do not fit this scenario, but most ranchers do.

6.4 Land Conversions

Land conversions between 1967 and 1975 for the non-federal lands are shown in Fig. 70 (383). Surface-mined lands are probably included in "other." These data show an increase in pasture and rangeland with large net increases coming for forestland and from cropland. In the northern Great Plains states, there was a loss in rangeland from 1967-77, averaging 5% (Table 44, 240) while the southern Plains gained rangeland, averaging about 12%. In the central Plains Kansas and Oklahoma lost while Colorado gained. However, it is not clear from the data whether the change was from forestland or cropland, or whether it occurred in the Plains grass[illegible] or in the western forests.

In South Dakota, rapid break-out o[illegible]geland for wheat beginning in 1973 attracted attention and data were tabulated by the Soil Conservation Service. Appreciable amounts of rangeland were transferred to cropland, resulting in an increase of about 1.6 m acres of cropland, a loss of 1.7 m acres of rangeland

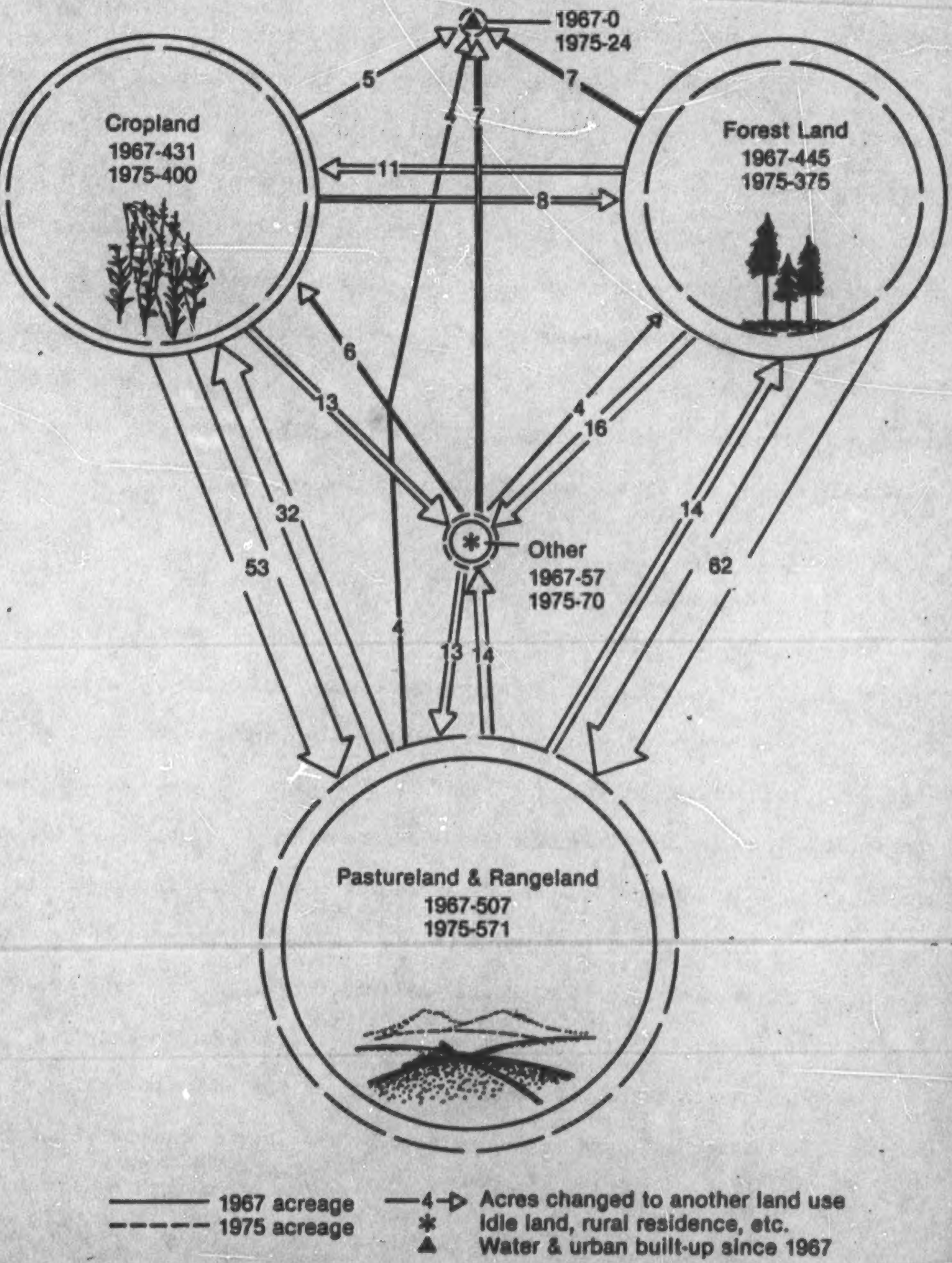

1967-0
1975-24
5
7
4
7
Cropland
1967-431
1975-400
Forest Land
1967-445
1975-375
11
8
6
13
4
16
32
53
14
62
Other
1967-57
1975-70
4
13
14
Pastureland & Rangeland
1967-507
1975-571
1967 acreage
1975 acreage
4 Acres changed to another land use
✱ Idle land, rural residence, etc.
▲ Water & urban built-up since 1967

Figure 70. Land use conversions between 1967 and 1975 (millions of acres, 383).

Table 44. Change in Area of Non-federal Rangeland in the States Containing the Great Plains from 1967 to 1977[1]

Region	State	Area, 1000 a			Change,
		1967	1977	Change	%
Northern Great Plains	Montana	41,322	38,833	-2,489	-6.0
	Wyoming	27,009	26,171	-838	-3.1
	North Dakota	11,076	10,564	-512	-4.6
	South Dakota	22,780	22,199	-581	-2.6
	Nebraska	23,884	22,001	-1,883	-7.9
	Region	126,071	119,768	-6,303	-5.0
Central Great Plains	Colorado	21,291	23,802	+2,511	+11.8
	Kansas	16,523	16,272	-251	-1.5
	Oklahoma	14,713	14,569	-144	-1.0
	Region	52,527	54,643	+2,116	+4.0
Southern Great Plains	New Mexico	37,520	42,096	+4,576	+12.2
	Texas	85,605	95,401	+9,796	+11.4
	Region	123,125	137,497	+14,372	+11.7

[1] From Pendleton and Schmude (1979, 240).

and a gain of 1/3 m acres of introduced pasture and hay (Table 45, 241, 245). About 11% of South Dakota's rural, non-federal land is in range which has no serious limitations as to crop production other than climate (Table 46, 241, 242). The Soil Conservation Service expects that many of these lands will be converted to cropland by 2030 (Fig. 71, 383). Most of the rangeland lies in land capability aggregate 6 and most of the cropland in aggregates 1 and 2. The most alarming thing about the break-out was that 53, 64, 56, 55 and 58% of the break-out, respectively for years '74-'76 through '79-'80, were in land capability classes unsuited for cultivation--Class IV through VII (Table 47, 241, 242, 243, 244, 256, 246).

The break-out began when fossil fuels were cheap, interest rates were relatively low, cattle prices were very low, wheat prices were good with prospects for even better prices and weather was fairly favorable. There appeared to be a good probability of increased income. However, adjacent to many of the newly-broken areas were the National Grasslands, purchased with emergency funds and returned to grass 40 years before. Some acted believing that they might hit a bumper crop and make a fortune, that if they had a crop failure government disaster payments would keep them in business, that they might be able to sell the land as cropland and turn a good profit, and, if worst came to worst, the government would help them seed the land back to grass. Thus, federal policy was partly, if not largely, responsible for much of the break-out.

At present costs and present interest rates the cost of reseeding these lands with native grasses is greater than the productive value of the land. Even if government cost sharing made the conversion economical, sufficient seed of local ecotypes of native grasses would not be available. Even if the land is seeded to one or two native grass species successfully, the range with 30 or

Table 45. Land Use Conversion in South Dakota, 1967-1980[1]

Year	Rangeland Grazing + Hay 1000 a	Rangeland Grazing + Hay %	Introduced grassland Grazing + Hay 1000 a	Introduced grassland Grazing + Hay %	Cropland 1000 a	Cropland %
1967	24,561	55.00	2,444	5.47	15,740	35.25
1975	23,533	52.70	2,612	5.85	16,819	37.66
Change, 1967-1975	-1,028	-2.30	+168	+0.38	+1,079	+2.41
1980	22,848	51.16	2,766	6.20	17,350	38.85
Change, 1975-1980	-685	-1.54	+154	+0.35	+531	+1.19
Change, 1967-1980	-1,713	-3.84	+323	+0.73	+1,610	+3.60

[1] Data from USDA Soil Conservation Service (1976, 241), (1980, 245). Acreages are rounded to the nearest thousand acres. Percentages were calculated before rounding.

Table 46. Land Use Conversion in South Dakota by Land Capability, 1967-1975 as Percentage of Rural, Non-federal Land[1]

	Land capability aggregate and subclass						
	1 I, IIc,s,w, IIIc,s,w, IVw	2 IIe, IIIe	3 IVe	4 IVs	5 Vw, VIw	6 VIe,s, VIIe,s, VIIIe,s	Total
Range, 1967	5.62	7.22	6.60	0.68	1.36	29.52	51.01
Change 1967-1975	-0.57	-0.95	-0.33	+0.09	+0.10	-0.13	-1.79
Cropland, 1967	16.84	14.09	2.72	0.48	0.08	1.04	35.25
Change 1967-1975	+0.20	+1.26	+0.52	+0.06	-0.04	+0.43	+2.43
Permanent hayland, 1967	1.85	2.21	0.77	0.16	0.23	1.22	6.45
Change 1967-1975	-0.18	-0.39	-0.04	+0.03	+0.03	-0.27	-0.82
Pastureland, 1967	1.25	1.11	0.35	0.03	0.06	0.22	3.01
Change 1967-1975	+0.20	+0.29	+0.09	+0.03	+0.01	+0.06	+0.68

---

[1] Data from USDA Soil Conservation Service (1976, 241, 242).

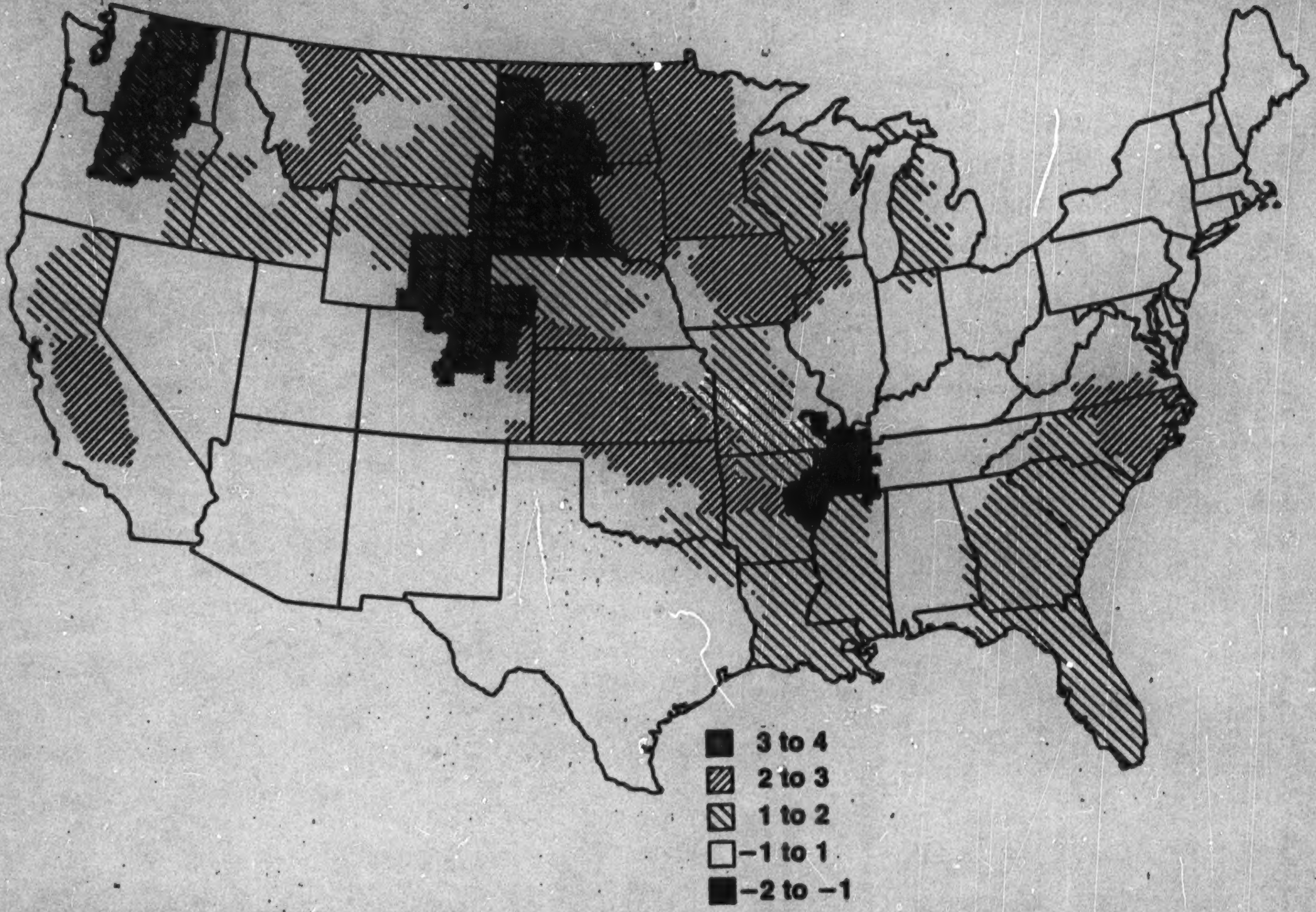

3 to 4
2 to 3
1 to 2
−1 to 1
−2 to −1

Figure 71. Projected changes in cropland acreage for the year 2030, by producing area (millions of acres). (Projected export level, 1977 production and erosion levels, 383).

Table 47. Cropland and Rangeland-to-Cropland Conversion by Land Capability in South Dakota 1967 to 1980, as Percentage of Rural, Non-federal Land[1/]

	Land capability aggregate and subclass						
	1 I; IIc,s,w; IIIc,s,w; IVw	2 IIe; IIIe	3 IVe	4 IVs	5 Vw; VIw	6 VIe,s; VIIe,s	Total
Cropland, 1967, %	47.8	40.0	7.7	1.4	0.2	3.0	100.0
Rangeland-to-cropland, 1974-1976, %	18.0	29.0	20.0	9.0	2.0	22.0	100.0
Rangeland-to-cropland, 1976-1977, %	14.0	22.0	19.0	14.0	2.0	29.0	100.0
Rangeland-to-cropland, 1977-1978, %	17.0	27.0	21.0	7.0	1.0	27.0	100.0
Rangeland-to-cropland, 1978-1979, %	17.0	28.0	16.0	13.0	1.0	25.0	100.0
Rangeland-to-cropland, 1979-1980, %	18.0	25.0	20.0	15.0	1.0	22.0	100.0
Cropland, 1980, %	44.3	40.2	8.8	1.8	0.2	4.7	100.0

[1/] Data from USDA Soil Conservation Service (1976, 241, 242; 1977, 243; 1978, 244; 1979, 245; 1980, 246).

40 species and with its marvelous adaptation and integration has not been restored.

Yet, demand for wheat is strong with expectations of sustained exports to the Soviet Union, China and other parts of the world. Wheat futures are trading at over $5 a bushel with some traders predicting $6 early in 1981. Technology of dryland agriculture and wheat production continues to improve, although limits to production increases are being reached (438). Nevertheless, thousands of acres of clean-tilled wheatland on class IV, VI and VII land bring back nightmares of the Dust Bowl.

6.5 Optimum Combination of Rangeland, Introduced Pasture and Cropland

Rangeland, introduced pasture and cropland can complement each other in a ranching or farming operation. The optimum proportion of these lands depends on 1) the capability of the land, 2) the kind, amount and value of the products, 3) the costs of production, 4) the level of technology, 5) the seasonal requirements for feed and forage, and 6) availability and cost of capital. Further, it is best to change from rangeland to cropland only after very careful consideration, because once destroyed the complex range ecosystem cannot be replaced quickly or cheaply.

Generally, cropland should not be placed on land capability classes IV and higher. While introduced pasture usually provides sufficient protection from erosion (although there are exceptions), stands usually decline in production and are often invaded by native plants (462). Nitrogen fertilization has been recommended for revitalizing "sodbound" crested wheatgrass (453). In view of the high cost of nitrogen fertilizer and the relatively low yield responses in dry subhumid and semi-arid regions, it seems better to view introduced grass pastures as long term crop rotations and put them on arable land only. Grazing-type alfalfas may lengthen the productive period of the pasture and hence the length of the rotation.

Harvested forage crops properly stored can stabilize the operation and provide protection against the hazards of snow cover, blizzard, drought, hail and grasshoppers. Furthermore, labor, equipment, fossil fuels and fertilizer can be substituted for land to increase the size of the operation without increasing acreage. Farmed forages for graze-out and introduced pasture can be used to complement native range as shown in Table 48 (452) for the southern Great Plains. McIlvain comments as follows, "By now it can be seen that the essence, or major value, of weeping lovegrass as tame pasture is quantity. The essence of wheat-sudan as farmed forage for graze-out is quality. The essence of native range is that it exists, it needs to be used for man's food ...and it provides stability and flexibility to complementary pasture systems. In return, the systems greatly increase beef production and economic returns from native range, and the systems can be used as tools for range improvement. Mutual dependence is real.

"The philosophy of complementing low-producing, rough grasslands with high-producing tame pastures or farmed forages, or both, opens the door to: (1) fitting green forages into dry periods, (2) opportunity grazing or resting of each forage resource for its proper development and use, (3) avoidance of grazing during periods when poisonous plants are highly hazardous, (4) use of flushing pastures...(5) use of breeding pastures, (6) use of the day-night rotations...(7) use of dehydrated forages for concentrates...and (8) use of high-quality feed as green creeps for calves or steers needing a rapid gain and following them with cows or younger steers to clean-up graze. In short,

Table 48. Generalized Beef Production Data and Economic Returns from Four Grazing Systems, 1966-72 (452)

Grazing system	Acres per steer	Gain per steer	Gain per acre		Returns per acre[1]	
	no.	lb.	lb.	% of NR	$	% of NR
1. Native range	8.8	390	44	---	3.85	---
2. NR + lovegrass	5.0[2]	360	72	164	6.40	165
3. NR + wheat-sudan	4.5[3]	420	93	211	10.00	260
4. Lovegrass + wheat-sudan	2.0[4]	370	185	420	13.50	350

Generalized yearlong data

[1] Net returns to labor and risk based on prices in 1971-72 starting with 400-lb steer calves in October at $60.00/cwt = $240; plus expenses of $12 cake, $4/acre NR, $14/acre lovegrass, $24/acre wheat-sudan, $18 interest, $12/ton haying costs, $8 death and vet, $6 buy-sell-haul, $1 taxes, or $80 total expenses on NR; and sale price of $45 cwt on 760-770-lb steers, $44.75 on 790-lb steers, and $44.50 on 820-lb steers.

[2] 4.5 acres NR plus 0.5 acre lovegrass.

[3] 3.5 acres NR plus 1 acre wheat-sudan.

[4] 1 acre lovegrass plus 1 acre wheat-sudan.

complementary pastures can be powerful forage production and beef production tools, and I believe we have just made a start in understanding and using their potentials here in the Great Plains."

Lorenz presented grazing plans for the northern Great Plains for combining native and introduced pastures with fertilization (Table 49, 454). Other studies throughout the Great Plains show the potential of introduced grasses and forage crops for increasing yields (463, 464, 465, 466, 467, 468), although comparisons usually have been made with deteriorated rangeland, rather than with range in high range condition. With increasing costs of production and limited availability of capital at high cost, introduced grasses and farmed forages are less economical. Limited resources of high cost must be used where they will give the greatest rate of return, not on lands where their use is marginal.

The technology for the complementary use of harvested forages, farmed forages for graze-out, introduced pasture and native range is generally worked out, although some details need investigation. However, these practices should be used only on arable land. These practices should be used only if careful economic analysis shows a good return on investment. The analysis should include realistic estimates of such frequently omitted items as the risk of stand failure and stand loss, longevity of the stand, costs of inputs, stocking rate estimates over time, and present value of future net returns determined with realistic interest rates. The response during drought should be evaluated, especially with regard to stand loss.

Table 49. Examples of Methods for Increasing Livestock Numbers on Great Plains Grasslands, Based on Data from Grazing Investigations at the Northern Great Plains Research Center, Mandan, North Dakota (454)

	Grassland combination[1]	Acres	Acres/ head[2]	Days grazing	Number of yearling steers	Avg. acres/ head
Example A:						
Case 1	Native	320	6.50	140	49	6.5
Case 2	Crested wheatgrass	62	0.96	40		
	Native	258	4.00	100		
	Totals	320		140	65	4.9
Case 3	Crested wheatgrass + N	43	0.62	40		
	Native	277	4.00	100		
	Totals	320		140	69	4.6
Case 4	Crested wheatgrass + N	56	0.62	40		
	Native	199	2.18	80		
	Russian wildrye + N	65	0.71	50		
	Totals	320		170	91	3.5
Case 5	Crested wheatgrass + N	64	0.62	40		
	Native + N	182	1.75	80		
	Russian wildrye + N	74	0.71	50		
	Totals	320		170	104	3.1
Example B:						
Case 6	Native	320	6.50	140	49	6.5
Case 7	Crested wheatgrass	77	0.96	40		
	Native	320	4.00	100		
	Totals	397		140	80	4.9
Case 8	Crested wheatgrass + N	50	0.62	40		
	Native	320	4.00	100		
	Totals	370		140	80	4.6
Case 9	Crested wheatgrass + N	91	0.62	40		
	Native	320	2.18	80		
	Russian wildrye + N	104	0.71	50		
	Totals	515		170	147	3.5
Case 10	Crested wheatgrass + N	114	0.62	40		
	Native + N	320	1.75	80		
	Russian wildrye + N	130	0.71	50		
	Totals	564		170	183	3.1

[1] N indicates 40-N applied annually.

[2] Based on long-time averages from grazing studies at the Northern Great Plains Research Center, Mandan, N. Dak. except for the native in Cases 5 and 10 for which the 1.75 acres/head was extrapolated from other production data.

6.6 Some Alternatives for Increasing Net Ranch Income

6.6.1 General Remarks

Many experts have suggested a vast number of ways for ranchers to make more money--some practical, much impractical. Basic considerations are the wise management of the land, livestock and management subsystems as discussed briefly in section 6.3 Large numbers of references have been given for the land and management subsystems, with less emphasis on the grazing animal per se which is covered in detail in various review articles (469) and in texts of beef and sheep production.

In the context of this report, we would like to discuss possibilities in three different areas.

6.6.2 Minimum Use of Cultural Energy in Meat Production

6.6.2.1 Role of Ruminants

Ruminants are inherently less efficient than monogastric animals in converting high-quality, low-fiber feeds to human food (Table 50). However, by virtue of symbiotic microbial activity in the rumen, ruminants can convert low-quality, high-fiber feeds into very high quality human food, as well as milk, fiber and work (471, 480, 481). Simple-stomached animals, such as swine and poultry, compete with man for food grains. Such animals may be reduced to the role of scavengers (473) if high population pressures force direct competition with humans for food grains. U. S. beef production methods using high concentrate rations, has been severely criticized by those concerned with the world food problem (458 and review, 474), who seem quite unaware of the potential for producing beef from grass. "If all the grain currently fed to livestock

Table 50. Efficiency of Meat Production by Different Animal Species Fed Rations for Optimum Production (modified from 432)

	Efficiency	
Animal species or product	Feed gross energy, Mcal / Food gross energy, Mcal	Feed digestible energy, Mcal / Animal gain, kg
Pork	5.9	2.8
Milk	6.7	---
Poultry	8.3	2.1
Rabbit	11.1	2.9
Eggs	14.3	---
Lamb	20.0	4.6
Beef	25.0	5.4

Table 51. Efficiency of Food Production in Terms of Cultural Energy Expended (modified from 432)

Food source	Cultural energy, Kcal / Food, Kcal
Rice	0.20
Wheat	0.23
Corn	0.24
Soybeans	0.33
Rabbit	1.67
Range lamb	2.00
Hog	2.50
Poultry	3.33
Steer (forage-fed)	3.33
Steer (grain-fed)	5.00

in the United States were consumed directly by people, the number that could be fed would be about 400 million, or less than 10% of the world population today. Exporting all of this grain would provide the United States with an added $15 billion annually (441)." However, the production of eggs, broilers, and hogs will probably continue to depend on grain. "Each of these livestock systems produces animal products having distinct advantages in the U. S. food system and offering benefits in efficiency of energy, land, and labor resources. They also contribute to the high nutritional quality of U. S. diets (441)."

6.6.2.2 Beef Production

To date most of the expansion in the beef cattle industry has come about through increasingly intensive management with heavy dependence on fossil fuels. "Fossil fuel energy use was estimated to vary from 5.1 to 11.6 Mcal per pound. Per capita consumption in 1976 was 129 pounds of beef or 658 to 1493 Mcal per capita. The equivalent in gasoline would be 19.7 to 49.8 gallons per capita which might be compared to the use of 50 gallons of gasoline for driving 1,000 miles in an automobile with a gasoline consumption of 20 miles per gallon (440)."

Cultural energy efficiency of livestock production is significantly less than for grain production (Table 51), with rabbits and lambs being much more efficient than beef cattle. An interesting experiment conducted at the Eastern Colorado Experiment Station, Akron, compared confinement, partial confinement with range production each at two planes of nutrition for the production of beef from weaning calves (Table 52). In this study cultural energy costs were carefully calculated for machinery construction, repair, and operation, pesticides and various agricultural chemicals as well as human labor, so that all inputs and outputs could be expressed on an energy basis. Cultural energy efficiency was much greater on range than in confinement. When performance was

Table 52. Efficiency of Meat Production, Cow-Calf Operation, Eastern Colorado Experiment Station, 1971-74 (recalculated from 434)

Confinement	Total, 12 mo.		Partial, 5 mo., Dec 1-May 1		None	
Range	None		Partial, 7 mo., May 1-Dec 1, 0.7 AUM/a		Total, 12 mo., 0.8 AUM/a supplemented with dehydrated alfalfa pellets, Nov. 1-May 1	
Daily TDN or Supplement level, lb.	6.5 TDN Jul 16-Apr 14	8.5 TDN Jul 16-Apr 14	6.5 TDN Dec 1-May 1	8.5 TDN Dec 1-May 1	1 Alf.	2 Alf.
Lactation ration, lb.	14 TDN Apr 15-Jul 15	14 TDN Apr 15-Jul 15				
Calf regime	Creep-fed till weaned, 90 days, bunk-fed to Oct 15	Creep-fed till weaned Oct 15				
Number of cows	23	23	30	30	30	30
Weaning wt., lb.	417	460	404	410	414	414
Calf weaned per cow bred, lb.	394	448	392	396	393	397
Cultural energy per cow, 1000 Mcal	31	37	13	15	8	9
Cultural energy per pound calf at weaning, Mcal	79	82	33	38	21	22
Cultural energy per pound of carcass, Mcal	141	146	59	67	37	39
Feed digestible energy, Mcal per carcass gross energy, Mcal	40	41	42	44	48	51
Feed digestible protein, kg per carcass total protein, kg	13	11	11	12	10	11

analyzed during four different seasons and allocation of resources determined to maximize either red meat production, cultural energy efficiency, digestible energy efficiency or digestible protein efficiency large differences were found (Table 53). Maximum beef production was obtained with a high plane of nutrition in total confinement for 3 of the 4 seasons with low cultural energy efficiency, low digestible protein efficiency and relatively high digestible energy efficiency. Cultural energy efficiency was maximized with range and partial confinement with a large reduction in meat output.

Calculation of efficiency of production of several typical livestock operations (Table 54) indicates that the range ewe-lamb operation is the most efficient in use of cultural energy, followed by the yearling operation in which calves are purchased at weaning and sold off grass at about 810 pounds. The next most efficient was the cow-yearling operation in which calves were produced and carried to yearlings before slaughter at about 810 pounds. The feedlot operation was the least efficient (470). Cultural use for various options and phases of the beef production system in Colorado are shown in Fig. 72. The least energy intensive system from birth to 1100 lb requires 3379 Mcal of cultural energy (3.1 Mcal per pound) compared with 7641 (6.9 Mcal per pound) for the most energy intensive system. Slaughter at 700 lb. resulted in the most efficient use with a low of 1262 (1.8 Mcal per pound).

When the diverse resources of a small (1618 ha) ranch in the Sacramento Valley of California were allocated using goal programming with highest priority to either 1) maximize meat production or 2) minimize fossil fuel requirement or 3) maximize profit, very large differences were found (Table 55). Maximizing meat production meant high use of fossil fuels, intensive land management, heavy supplementation and low ranch returns. Minimizing fossil fuel use

Table 53. Efficiency of Meat Production from Four Linear Programming Solutions, Eastern Colorado Experiment Station (modified from 434)

	Maximize			
	Red meat production	Cultural energy efficiency	Digestible energy efficiency	Digestible protein efficiency
Seasonal sequence[1]	C8½, R2, C8½, C8½	R1, R2, P8½, P6½	C6½, C8½, C8½, P6½	R1, C6½, C8½, P6½
Carcass weight index	120	104	100	100
Cultural energy, Mcal per carcass wt., lb.	11.6	4.4	11.8	7.5
Cultural energy, Mcal per carcass gross energy, Mcal	13.0	4.9	13.3	8.4
Feed digestible energy, Mcal per carcass gross energy, Mcal	41.3	46.9	39.3	47.6
Feed digestible protein, kg per carcass total protein, kg	11.2	10.3	10.8	10.1

---

[1] Data from four seasons (Apr 18-Jun 17; Jun 18-Aug 17; Aug 18-Oct 15; Oct 16-Apr 17) were entered separately. Feeding regime is abbreviated from Table 53.

Table 54. Efficiency of Meat Production from Typical Livestock Operations (470)

Kind of operation	Average weight or gain per individual, lb.	Cultural energy, Mcal per Live wt. or gain, lb.	Cultural energy, Mcal per Carcass energy, Mcal
Central Plains			
Cow-calf			
Range-sorghum, 250 cows	445	2.8	5.2
Range-250 cows	414	2.4	4.6
Yearling			
Range-sorghum, 400 steers	396	2.5	2.8
Cow-yearling			
Range for cows, range-sorghum yearlings	810	2.4	3.5
Feedlot fattening, 15,000 steers	586	8.1	5.3
Cow-calf (range)-feedlot	1000	5.7	5.2
Intermountain Great Basin			
Cow-calf			
Range-250 cows	405	2.2	4.1
Ewe-lamb			
Range-2000 ewes	86	1.5	2.2

Reducing Energy Use for Beef Production

Possibilities for reducing energy use in beef production can be divided into three groups: first, energy conservation within the current production system; second, a reduction in beef production; and third, alternative production strategies.

Energy conservation. Wasteful uses of energy were not found in our study of the beef industry. However, several marginal energy uses could be eliminated without adverse effects, and several new techniques would, if more completely adopted, reduce energy use.

One of the major energy uses in cow-calf production is transportation fuels for pickup trucks. Because of the large distances over which production occurs, great use is made of pickup trucks. Use of more economical vehicles would aid in this respect. Much of the grazing by cow-calf operations occurs year-round. For greater efficiency of pasture and range use, a trend toward semiconfinement in cow-calf operations might be considered. Greater numbers of cows could be supported by grazing only during the summer season when forage quality is good. Harvested roughages or residues could be fed during the winter season.

Feed processing is not a major energy use (*11*) compared to feed production, but energy use and benefits, such as weight gain response to energy inputs, need to be documented more carefully. Dehydrated alfalfa has been a widely recommended winter supplement for cattle in the West because it provides protein, as well as energy, phosphorus, and carotene. However, dehydrated alfalfa is one of the most energy demanding of feed-processing methods because of the need to dry immature plants. The use of 2 pounds of this feed per day for 6 months in winter can double the energy required to produce weaner calves.

Energy requirements for beef production are primarily associated with feed production. In the West, most feed production requires irrigation; and irrigation, if pumping is required, is energy-intensive (*3*). Energy has not been efficiently used for irrigation pumps in the past, and potential energy savings of 25 to 40 percent are suggested (*16*). After irrigation, nitrogen fertilizer is the major energy requirement for feed production in the West as well as in other parts of the country, except where legumes are grown. Some fertilizer-based energy could be saved by better conservation of

Table 5. Fuel energy use per unit of beef energy and energy of beef protein.

Range	Total	Energy input (Mcal)			
		Per carcass energy	Per retail beef energy	Per energy from carcass protein	Per energy from retail protein
			1100-pound steer		
Lowest	3379	3.0	6.7	16.0	19.7
Highest	7641	7.0	15.1	36.0	44.4
			700-pound steer		
Lowest	1262	2.0	4.4	6.6	8.1

ciency of protein utilization appear to be minimal. The only wasteful use of protein, if it can be called that, for example, is the grazing of cattle on young, high-protein grass, which contains more than the necessary protein. Otherwise, the amount of protein consumed by cattle, unlike the amount consumed by many people in the United States, is generally close to the minimum required for economic reasons. Many grazing cows in the winter, in fact, are fed less protein than desirable. Beef cattle on feed in 1974 consumed 1 million tons of protein supplements, and 0.7 million tons was fed to other beef cattle. This is a small fraction of the total of 19 million tons consumed by all livestock; poultry consumed 8.9 and hogs 5.9 million tons (*4*).

Urea is an important substitute for protein in cattle feeds, mostly in feedlots. However, urea production, like the nitrogen fertilizers, requires large energy inputs. Furthermore, urea has not proved to be an effective substitute for protein in diets composed of poorly digestible forage such as found in winter ranges and pastures.

Reduction in beef consumption. One suggestion, often voiced, to reduce energy use in beef production is to reduce the amount of beef produced. Although imports are not mentioned in relation to this solution, it is assumed that this 7 percent of the supply would not be increased. The nutritional consequences of a substantial reduction in the beef supply have not been analyzed, but two diverse conclusions can be drawn. One, a protein deficiency is a possibility because beef is a major source of high quality protein for some populations (*17*). The opposite conclusion, that a reduction in beef consumption would be desirable, can be drawn from a recent Senate committee report which recommends that

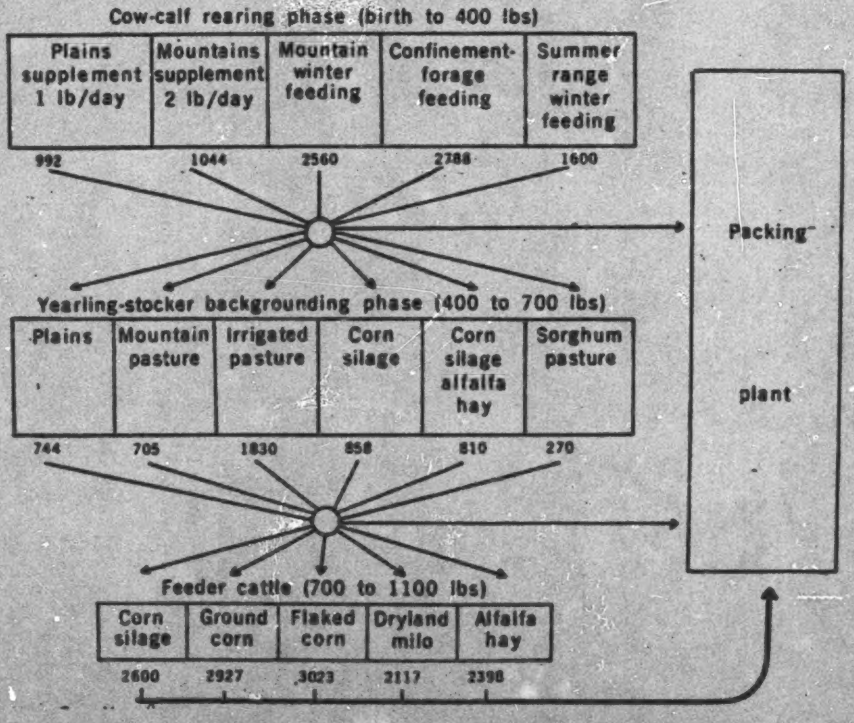


Figure 72. Cultural energy use for various options and phases of the beef production system in Colorado. Data expressed as megacalories of cultural energy (440).

Table 55. Results of Goal Programming with Highest Priority Goal Changing (431)

Item	Unit of measure	Highest priority goal: Maximize meat production	Highest priority goal: Minimize fossil fuel requirement	Highest priority goal: Maximize profit
Meat production	Kg	451,460	131,680	262,600
Fossil fuel need	Liters	649,040	51,820	246,150
Ranch return	Dollars	$ 15,880	$ 23,610	$120,310
Cow-calf	Units	1,596	0	1,092
Cow-calf-yearling	Units	0	477	0
Ewe/lamb	Units	1,358	0	0
Alfalfa sold	Metric tons	0	0	1.5
Barley sold	Metric tons	0	0	1,112
Labor	Hours	2,952	2,072	3,039
Farmland seeded	Ha	0	283	0
Improved range seeded	Ha	0	0	243
Improved range fertilized	Ha	243	0	0
Good range fertilized	Ha	202	0	0
Fair range fertilized	Ha	623	0	0
Brushland burned, sprayed and seeded	Ha	202	0	202
Supplement	Kg	113,400	0	0
Farmland barley fed	Metric tons	1,110	0	0
Alfalfa	Ha	65	0	60
Sudan	Ha	0	0	5
Irrigated pasture	Ha	0	65	0

resulted in only 29% as much beef production as alternative 1, land management was less intensive and returns slightly higher. Maximizing profit resulted in returns 7.6 times as great as maximizing meat production and 5.1 times as great as minimizing fossil fuel use and used 4.7 times as much fossil fuel as the latter. Land management was more intensive. Seven goal programming runs with meat production as highest priority, follwed by fossil fuel conservation, followed by profit with the goal level for meat production varying in each run (Table 56) showed that profit increased up to the 272,160 kg level and then began to decrease. Farmland (347 ha) was seeded to range, 124 ha brushland was cleared and 65 ha of alfalfa were used. Increasing meat production required progressive increases in labor, seeding, brushland clearing, supplemental feeding, barley feeding (rather than sale) and the addition of a ewe-lamb operation. As the costs of cultural energy continues to rise, minimization of cultural energy use may be nearly synonymous with maximization of profit. However, such a situation is not yet apparent.

Several authors have been concerned about energy use in agriculture (435, 437, 349) as well as in beef production (440, 441). Pimentel et al. (1980, 441) wrote that increasing the use of range and pasture "...for livestock production would not only reduce energy, land and labor inputs in livestock production, but would also reduce by about half the production of animal protein. The savings in energy, land and labor in moving toward a grass-fed system, however, would not be as large as suggested by the analysis, because some grain and other food resources would be consumed directly by the U. S. population as a substitute for the reduced intake of animal products (441)." Decreases in animal production would increase the price of beef and seriously offset the nutritional quality of American diets (441). However, it appears

Table 56. Results of Goal Programming with Meat Production as Highest Priority Goal, Fossil Fuel Conservation Second, and Profit Third with Different Levels of the Meat Production Goal (431)

Item	Unit of measure	Goal level for meat production (kg)						
		136,080	181,440	226,800	272,160	317,520	362,880	409,240
Fossil fuel need	Liters	51,820	54,330	57,850	62,810	101,400	227,780	404,310
Profit	Dollars	$ 25,330	$ 45,740	$ 57,460	$ 65,730	$ 58,140	$ 55,860	$ 40,240
Cow-calf	Units	0	755	943	1,132	1,321	606	817
Cow-calf-yearling	Units	462	0	0	0	0	0	0
Ewe/lamb	Units	0	0	0	0	0	4,350	4,243
Labor	Hours	2,072	2,159	2,280	2,491	2,678	2,848	2,996
Range fertilized	Ha	0	0	0	0	0	173	339
Range-farmland seeded	Ha	283	283	283	397	501	400	331
Brushland cleared	Ha	0	0	0	124	202	202	202
Supplement	Kg	0	0	0	0	113,400	113,400	113,400
Farmland barley fed	Metric tons	0	0	0	0	100	494	765
Irrigated pasture	Ha	0	45	18	0	0	0	0
Alfalfa fed	Ha	0	19	47	65	65	65	65

likely that the rancher, heavily influenced by the need to maximize profits, will move away from maximum beef production and will tend to reduce inputs of cultural energy if costs of these inputs rises faster than the price of beef, which certainly seems to be the case for the foreseeable future.

6.6.2.3 Combinations of Grazing Animals

The fact that a combination of grazing animals makes more efficient use of the range resource than only one is well established. Different animals have different preferences for range sites, topographic areas, plant species and parts of plants. Therefore, the greater the heterogeneity of these items the greater the advantage for combinations of herbivores. Cattle, sheep, goats and deer make more efficient use of Texas savanna than any one species alone (23). Cattle, bison, sheep, and antelope were not directly competitive in very uniform pastures of shortgrass in north central Colorado (21). Mule deer, elk and cattle were not directly competitive on the Missouri River breaks of eastern Montana (22). Advanced techniques for efficient allocation of forage to combinations of grazing animals are available and are being improved (see section 5). In spite of this fact, the range livestock industry is turning more and more to cattle alone.

Sheep numbers continue to decline in the United States for various reasons (475). High predator losses in the range area (476, 477, 478) and the difficulty of obtaining suitable labor at reasonable cost seem to be the major reasons for the decline of sheep. Increased numbers of coyotes and other predators following restrictions on the use of 1080 and other control agents have caused severe problems in some areas. Lamb has become a specialty meat, rather than being developed and advertized as a full competitor with beef and pork. Wool has continually lost ground to synthetics. However, cultural energy efficiency is much greater in production of cotton and wool than in the production of synthetic fibers (Table 57). Furthermore, the productive efficiency of sheep is 1.6 times greater than cattle (Fig. 56). Furthermore, as noted in the previous section (Table 51, 54), sheep are considerably more efficient than cattle with respect to cultural energy inputs. The sheep industry has much to offer for increasing net ranch income on Great Plains ranches as well as on the rangelands of the world (472).

Game ranches have been quite successful in South Africa (479) and also in the Texas savanna. Bison are rather common on ranches in the northern Great Plains and elk and bison are being grazed together on the Oglala Sioux Game Range in South Dakota (480). Wild game can also contribute to net ranch income through hunting leases and other arrangements. As pointed out in section 4, the best way to increase game numbers is to provide for the contribution of game to net ranch income, thus providing a direct financial incentive for the management of game habitat.

The productive efficiency of rabbits (433) is 3.3 times as great as cattle and 2.1 times as great as sheep (Table 58). Management problems in raising rabbits under range conditions would be immense in terms of fencing, harvesting, breeding and selection, protection from predators, etc. Yet, the productive potential is very great. Wild rabbits and rodents, likewise, have vast productive potential and are marvellously adapted to the range environment. Our principle concern has been control to minimize competition with livestock. Could these animals be managed to produce a product?

Prairie dogs were discussed in section 5 as tillers of the soil and as herbivores that are partially, but not directly, competitive with livestock and big game. The tillage effect probably could be used to stimulate plant

Table 57. Efficiency of Fiber Production (470)

Fiber	Cultural energy, Mcal/lb of fiber
Wool	8.3
Cotton	3.2
Non-cellulosic fibers (polyester, nylon, acrylic)	15.2
Cellulosic fibers	20.4

Table 58. Average Productive Efficiency for Cattle, Sheep and Rabbits When Supported Entirely on Rangelands on a Sustained Yield Basis (from 432)

	Cattle	Sheep	Rabbits
Animal unit equivalent	1.0	0.2	0.02
Offspring/100 females	90	120	1485
Weight per offspring, kg	182	39	0.9
Replacements per year, %	10	20	30
Offspring for export/100 females	80	100	1455
Exportable wt/female, kg	145	39	13
Metabolizable energy used per female and young per year, Mcal	8977	1544	245
Metabolizable energy used per kg of offspring exported, Mcal	61.9	39.9	18.8
Offspring exported, kg per Kcal metabolized energy used	0.0162	0.0251	0.0531
Efficiency index	100	155	328

production and control botanical composition by controlling prairie dog density and duration of occupation. If a limited number of prairie dogs were introduced into a new area, allowed to form open colonies, and then moved to a new area before high densities and resulting range deterioration began, range vegetation might be stimulated and a new source of meat produced with minimum competition to other grazing animals. Management problems would be immense, including social pressure and market discrimination. However, productive potential appears to be great enough to justify research in this area.

6.6.3 Diversification of Sources of Income to Maximize Flexibility

The importance of flexibility in the ranch business in order to meet unexpected changes in weather, markets and other hazards has been emphasized in other sections. Flexibility increases ranch costs, but in the long run can be expected to increase net ranch income. Cow-feeder yearling operations have more flexibility than cow-calf; cow-slaughter steer (forage-fed) have more flexibility than cow-yearling; operations with combinations of livestock and/or game have more flexibility than those producing only one species. Ranches with introduced pasture, forage crops and wheat produced on land suitable for crop production have more flexibility than livestock alone (unless costs are too high).

In addition, many resources and uses of Great Plains rangeland, listed in section 4, could be developed and incorporated into the management strategies of Great Plains ranchers to produce greater and more stable net ranch income. Yet, with the addition of every enterprise, with increasing complexity in every phase of the ranch business, greater and greater stress is placed on the manager. Never has there been a time when the pressure has been as great. Wise and full application of technology will be required for survival and successful competition. Yet uncritical adoption of intensive technology can result in bankruptcy and range deterioration.

6.7 Use of Leased Lands

As a heritage of the early land disposal laws, the ownership pattern of many Great Plains ranches resembles a checkerboard, although the problem is less than in the regions further west. Many ranches have privately-owned land intermingled with land leased from private parties, Indian tribes, states and the federal government. Privately-owned land may be leased from individuals, including Indian owners, railroads, insurance companies and other corporate owners. States received grants from the federal government for the support of education and the land-grant colleges. Some states have retained these lands and lease the grazing to ranchers. Indian tribes have retained ownership of much of their land which is often leased to ranchers through the tribal council. The National Grasslands, located primarily in the Great Plains, are administered by the Forest Service and lease grazing to ranchers. While most of the public domain lands administered by the Bureau of Land Management lie west of the Great Plains, ranchers lease grazing on sizable areas in the western portion of the region in Montana and Wyoming.

Use of leased land is often cheaper than using private land. However, some lease arrangements foster overuse because of improper lease agreements. Insecure tenure is often a problem promoting overuse and introduces instability in the ranching operation. If the lease rate is low and regarded as stable, income from animals grazing on the leased lands is often capitalized into the purchase price of the private lands when they are sold, resulting in the purchase of that for which no title is received. This has occurred in the sale of private ranches with long term leases on National Grasslands, Grazing Districts, State lands, Tribal lands, and other lands. If management priorities of the owners change, the rancher's lease may be modified or terminated. Often the development of range facilities and initiation of range improvement practices are more difficult because of the lease arrangement.

Leasing of grazing on the federal lands in the Great Plains appears to be more secure than in the western states, where political action by various user groups have challenged management decisions of the Bureau of Land Management and to a lesser degree the Forest Service. Even in the Plains, preparation of Environmental Impact Statements takes a fairly large portion of the time of federal range personnel (442), although much less than in the western states.

Generally, incorporation of leasing arrangements into the ranch operation permits expansion of livestock numbers and usually supports increased net ranch income. However, greater demands are made on management, especially if flexibility is to be maintained.

7. SOCIAL ACTION

7.1 Introductory Statement

The nation must have a keen and continuing interest in the management of its rangelands which comprise more than 40% of the contiguous United States and in the management of the rangelands of the world that make up nearly one-half of the earth's land surface. This interest must be expressed in the education of its citizens at all levels, technical assistance to land owners, economic incentives to assist in the application of sound management practices on the land, policies of state and federal agencies to foster good rangeland management, state and federal legislation designed to secure wise management and protection of resources on both public and private lands, and research to provide knowledge on which to base management decisions.

7.2 Education

7.2.1 Introductory Statement

The key to the wise management of both private and public rangelands is education. In the opinion of the authors, if all available, pertinent knowledge were applied with wisdom on Great Plains ranches, average net ranch income would be doubled, at least, while improving the land and providing for greater satisfaction of human wants. Substantial increases are also possible on public lands.

Educational challenges relate to 1) the preparation of rangeland managers and those who advise them; 2) the preparation of teachers and research workers in various components of range ecosystems, as well as the total system; 3) the preparation of teachers of non-rangeland topics and community, business and political leaders; and 4) education of the general public. Range education is failing to meet the challenges in each of these four areas. The most abysmal failure has been in the preparation of leaders and in the education of the general public. Individuals in the general population or in various echelons of government are rare indeed who have a perspective on the importance of rangeland, of its potential, or the problems of its management. This fact is brought sharply into focus by an examination of the three volumes of the document "Global 2000 - A Report to the President" submitted this year, prepared by experts from various government agencies. This document provides rather complete coverage of forestland and cropland and detailed perspective on a wide range of products and environmental problems, but only incidental mention of the rangelands which cover nearly half the land surface of the globe. Reference is made in connection with desertification, nomadic herding and forage for ruminants. The fact that rangeland covers nearly half of the land surface of the globe can be inferred by adding the area of different classes of land and subtracting to find the area of undescribed residue which is mainly the rangeland portion of the world. Range education has failed to do its job.

7.2.2 University Education

While some western universities offered individual courses in range management, the first curricula leading to majors in the discipline began immediately after World War II. The Range Management Education Council (later re-named the Range Science Education Council) was organized in 1959 and played an active role in the development of range science education. The Range Science Education Council and the Professional Affairs Committee of the Society for Range Management have worked actively for strengthening professional standards for employment by the federal government as a range conservationist. New standards were published in 1980 requiring a B.S. degree in Range Science or a closely allied field with a minimum of 18 semester hours of Range Science (443). The new standards have been needed very urgently for a long time. In 1974, 42% of the range conservationists in federal service did not have a degree in Range Science, but "qualified" by taking 12 semester hours of range courses (483). Although the new standards are a definite improvement, many range educators feel that they did not go far enough. Further strengthening will be needed as range science increases in depth and complexity. Formal university education with a major in Range Science is offered now at all of the land-grant colleges in the 17 western states and at a number of other universities. All of the curricula treat rangelands as a particular kind of land providing a wide range of resources and uses. Graduate degrees are offered at a number of universities. One of the major weaknesses of present university education in range science in the light of future needs is the lack of preparation for the use of computers and mathematical decision-making tools for management of both public and private lands. New textbooks are needed as well as better use of slides, films, closed circuit and educational television.

A large number of options in the Range Science major are needed to help students who plan to work with particular uses of range ecosystems. Most of these students now take degrees in other majors with few range courses or none at all. During their subsequent professional careers, these people often fail to see rangelands as kinds of land with many resources and fail to see the essential unity underlying the manifold uses of rangeland. An attractive minor in Range Science listed in the catalog should attract some of these students into taking more range science courses. It is imperative that those who manage the uses of range ecosystems understand the nature and management of the ecosystem that supports those uses. At the present time, this is not being done to the extent that it needs to be done. Furthermore, range science courses are not attracting a sufficient number of students from other disciplines and other colleges in the universities. The academic community, both professors and students, are largely unaware of the importance of rangelands, their potential, their problems and their management needs. In many cases they seem to be unaware of their existence.

The scientific knowledge of many range professionals is badly out of date and, in some cases, basic scientific principles have been forgotten. Rapid progress in range science and associated disciplines requires that knowledge in the field be updated continually through scientific journals, meetings, books, colloquia, etc. Furthermore, employers of professional range technicians and scientists need to provide frequent training sessions, as well as educational leaves for their employees to pursue advanced degrees and to attend special courses and workshops designed to keep them abreast of recent knowledge. The universities, in turn, need to plan and implement such activities.

7.2.3 Primary and Secondary Education

Primary and secondary school teachers do not receive instruction about rangelands, regardless of their discipline. Even those students attending land-grant universities who plan to teach agriculture in the Great Plains region usually take no courses in range science, or only one or two at the most. Students receiving their education at other schools receive no information about the extent, importance, condition and management of rangelands. Consequently, there is essentially no instruction being provided to the children in the public schools of our nation regarding our rangelands. Exceptions are the teachers who have seen the need and prepared themselves to teach range science topics to their pupils. Other exceptions are Range Youth Camps, coordinated through the Society for Range Management and the Extension Service, usually with cooperation of many professional range scientists from various employers, and 4-H range programs through the Extension Service. However, these are all for rural youth.

At the present time the average citizen, even in the Great Plains region, knows essentially nothing about rangelands and their contribution to the well-being of the world or of the United States. To help remedy this deplorable situation, textbooks in Social Studies and Geography for elementary, middle school and high school students should include sections on rangeland. Preferably, these sections should be prepared by, or at least reviewed by, the Society for Range Management or by individuals knowledgeable in range science.

7.2.4 Vocational and Technical Schools

The Ranch Program at Texas Christian University, Ft. Worth, Texas offers an intensive two-year curriculum in ranch management with a strong reputation. Students entering this program are often university graduates with experience. In general, however, range science does not receive emphasis in vocational and technical schools even in the range region.

7.2.5 Adult Education

7.2.5.1 Agricultural Extension Service

The first State Range Extension Specialist position was established in Texas in 1947. Now there are several specialists at the state level and range extension specialists in various regions in Texas. A State Range Extension Specialist position was established in South Dakota in 1978. There is still no National Range Extension Specialist position in the Extension Service. Although, the situation is improving, especially in Texas, most county agents in the Great Plains region have had no courses in range science or only one or two. Very often county agents do not feel comfortable with range education projects and programs and depend on the Range Extension Specialist to supervise such meetings or programs. Consequently, there is inadequate time for the development of Extension publications synthesizing range science with applications to local problems, and inadequate time for the preparation of movies, slide shows, and teaching materials which can be used by others. Some states have demonstration ranches. Careful measurements made on exemplary private ranches have been used to a limited degree. This approach needs much more emphasis. Some states have developed extension districts combining several counties in which different agents specialize in different disciplines, thus providing better information for their constituents, but at higher travel costs. Rangeland management should receive additional funding and greater emphasis in the Extension Service as a result of the passage of the Renewable Resources Extension Act of 1978.

Practically all of the activities of the Extension Service, especially those related to rangelands are directed toward rural people, primarily landowners leaving the bulk of the population completely uninformed about the range.

7.2.5.2 Other Agencies

The Soil Conservation Service places a major effort in the education of individual operators regarding range management. Many District Conservationists as well as Range Conservationists have degrees in Range Science, although this is quite variable by state. In 1978, the Soil Conservation Service had more foresters on its staff than range conservationists in Nebraska, a major Great Plains range state. Forest Service also provides educational services on an individual basis in areas near the National Grasslands and the National Forests. Both agencies provide valuable publications. The Bureau of Land Management also exerts educational influence in those areas where public domain lands occur.

7.2.5.3 Society for Range Management

The SRM provides education through its journals (Journal of Range Management and Rangelands) science series, and other publications from the international office at Denver; annual meetings; sponsorship of rangeland congresses; interaction with other scientific societies; position statements and expert testimony on issues affecting rangelands; range tours; and section meetings, tours, newsletters and position statements at the local level. From 1975-78, the Society administered a grant from the Old West Regional Commission to strengthen range management in Montana, Wyoming, North Dakota, South Dakota and Nebraska. This program made an effective contribution in securing the application of good range management on the land. This program also prepared a movie describing range management for urban groups (481) and a number of one-minute public service sequences for television to call attention to rangelands.

There is a large and continuing need for educational materials of all kinds about rangelands, especially those directed toward the urban segment of our population.

7.2.5.4 Other Private Organizations

Banks, other lending agencies, and various private companies have occasionally been involved in the dissemination of information regarding range management or in sponsoring of workshops or other activities.

7.2.6 Summary

A powerful, coordinated educational effort is needed at all levels to disseminate existing knowledge about rangelands, in order to secure wise management of these lands and wise public policy regarding them. All types of educational materials ranging from professional reference books, university textbooks, and movies to elementary school materials and public service features for television are needed.

7.3 Technical and Financial Assistance

A major function of the Soil Conservation Service (SCS) (established in 1935) is to provide technical assistance for landowners organized in Soil Conservation Districts. The SCS establishes Standards and Specifications for conservation practices. Ranchers can request technical assistance from the SCS through their Soil Conservation District in planning and implementing conservation practices (444). Planning and technical assistance are also offered through the Great Plains Conservation Program (GPCP), the Watershed Protection and Flood Prevention Program (WP & FP), the Resource Conservation and Development Program (RC & D) and the Agricultural Conservation Program (ACP) administered by the Agricultural Stabilization Conservation Service (ASCS). The SCS can provide technical assistance for mining activities in a way similar to that for agricultural activities. The ACP program, initiated in 1936, provides financial assistance by cost-sharing the cash expense of establishing conservation practices in accordance with SCS Standards and Specifications when certified by SCS technicians. The ACP program includes regular and long-term agreements of 3 to 10 years. The long-term agreements are available only in those areas not covered by the Great Plains Conservation Program, which was authorized in 419 counties in the ten Great Plains states in 1956. In 1978, cost-share payments of $51.1 million were distributed to 73,725 participating farms and ranches in the ten Great Plains states (Table 59) with total payments ranging from a low of $1.9 million in New Mexico and Wyoming to $15.4 million in Texas. The percentage of the total used in range-related practices ranged from 26% in New Mexico to 73% in Oklahoma. Oklahoma, Texas, Montana, South Dakota and North Dakota used from 49 to 73% on range with the other states varying from 26 to 33%, probably due to the relative emphasis on these programs by the U.S.D.A.

Table 59. Cost-Sharing Activities of the Agricultural Conservation Program in the Great Plains States, 1978 (445)

State	Number of participating farms	Payments: Dollars, Total, million	Payments: Dollars, Per farm	Payments: % of total for rangeland-related practices
Montana	4,409	4.6	1,100	54.9
Wyoming	1,558	1.9	1,280	33.3
Colorado	2,842	3.5	1,269	28.7
New Mexico	1,429	1.9	1,367	25.8
North Dakota	12,316	4.9	419	48.6
South Dakota	9,098	3.0	353	54.2
Nebraska	6,644	4.8	742	28.9
Kansas	6,940	5.7	853	28.5
Oklahoma	8,440	5.3	650	72.6
Texas	20,044	15.4	790	68.1
Great Plains States	73,725	51.1	693	---

We do not have comparable data for the Great Plains Conservation Program in all of the states. However, in South Dakota in the year ending September 30, 1979, $962,847 was used for cost-share of which 72.0% was for range-related practices. The total used on the GPCP was about one-third of that on ACP but with a much higher percentage on range (72 versus 54%). Since the GPCP program began in 1956, $13.9 million have been used for cost-sharing through September 30, 1979 of which 81.7% has been for range-related items. Of the total expended to cost-share range-related practices, 60% has been for water developments and 29% for seeding activities (Soil Conservation Service, State Office, Huron, S.D., personal communication).

Both the ACP and GPC programs have been effective in getting conservation practices applied. The GPC program which involves a complete conservation plan and a contract for a specified time period with planned followup has been especially effective. The National Cattlemen's Association, the Society for Range Management, the National Association of Conservation Districts and several other organizations passed resolutions supporting passage of the enabling legislation for the extension of the GPC program from 1981-91.

Low cost loans are also available through the Resource Conservation and Development program and through the Farmers Home Administration for various aspects of soil and water conservation (383). FmHA is authorized to make the following loans related to rangelands: operating loans, farm ownership loans, soil and water loans, grazing association loans, recreation loans, watershed loans, resource conservation and development loans, emergency loans and economic emergency loans.

7.4 Federal Rangeland Policies

7.4.1 Present Federal Policies

7.4.1.1 Background

Grazing management research was initiated in the middle '90s in response to the recognition of the problems caused by overgrazing. Experimental work was increased by both federal and state governments during the teens and twenties. Grazing management was used on the national forests shortly after their establishment in 1905. In 1914, Sampson wrote, "Ideal range management would mean the utilization of the forage crop in a way to maintain the lands at their highest state of productiveness and at the same time afford the greatest possible return to the stock industry (496)." In 1919 Jardine and Anderson clearly articulated the multiple use concept. "...grazing on the National Forests is regulated with the object of using the grazing resources to the fullest extent possible consistent with the protection, development, and use of other resources....As the National Forests were established primarily for the protection and development of the Forests and the protection of the watersheds, great pains must be taken to harmonize grazing with these primary purposes. Also...more and more care must be exercised to see that the wildlife of the Forests is not unduly restricted....The recreational features of the National Forests, too, are of increasing importance, and increased attention is necessary to harmonize grazing use with recreational use" (497).

Sampson's three textbooks on range management were published during the twenties. The McSweeney-McNary Forest Research Act passed in 1928 gave impetus to research on rangelands. However, these activities appeared to have little influence on the management of the private lands and the public domain lands.

Large acreages of range were plowed and put into wheat during World War I in an all out effort to produce food. Soil erosion was not a serious concern until publicized by Hugh Bennett, whose voice began to be heard about 1928 (498). With the decline in export markets after the close of World War I, prices dropped because of oversupply. Depression, drought and severe erosion alarmed the nation in the early '30s calling forth a flood of new legislation, geared mainly for croplands, but with application for ranges as well.

The new laws were designed to deal with crop surpluses and with wind and water erosion on cropland and to some degree on rangeland. A Forest Service evaluation of range condition showed that more than half of the nation's rangelands were in a state of severe or extreme depletion. The Forest Service lands were depleted less than the others (499). During this period of time the Soil Conservation Service, Soil Conservation Districts, A.S.C.S. and the ACP program were established and a program of research, demonstration, education, technical assistance, and cost-sharing was begun on soil erosion and related areas. Participation in these programs was entirely voluntary (500) and while impressive was never complete.

During this period the Taylor Grazing Act of 1934 was passed regulating grazing on the public domain lands and the Grazing Service was established. Bankrupt and eroding farms were purchased with funds from the Bankhead-Jones Act of 1937, creating the Land Utilization projects, later the National Grasslands.

Technological advancements and the demand for food revolutionized cropland agriculture following World War II, but with the reduction in demand in the post-war period resulted in food surpluses in the '50s and '60s giving rise to a series of complex farm programs designed to reduce production, maintain farm income and reduce erosion. Generally, rangelands were not topics of policy discussion during this period. Ranchers did not request federal assistance and the only federal programs directly influencing the rangelands were the ACP and the GPCP. Attention was focused on cropland and forest land, while rangelands were taken for granted and largely ignored.

The passage of the Classification and Multiple Use Act of 1964, Water Resources Planning Act of 1965, and Water Quality Act of 1965, were the result of a greater interest in the environment, as was the air pollution legislation beginning in 1955, followed by a long series of amendments. Some of these laws contained mandatory stipulations with penalties for failure to comply.

Following these have come an avalanche of legislation impacting both private and public rangelands. Some of the more important pieces of legislation are the following: National Environmental Policy Act of 1969; Federal Water Pollution Control Act of 1972; Forest and Rangeland Renewable Resources Planning Act of 1974; Federal Land Policy and Management Act of 1976; National Forest Management Act of 1976; Soil and Water Resources Conservation Act of 1977; Rural Clean Water Act of 1977; Surface Mining and Reclamation Act of 1977; National Agricultural Research, Extension and Teaching Policy Act of 1977; Soil and Water Resources Conservation Act of 1977; Public Rangelands Improvement Act of 1978; Renewable Resources Extension Act of 1978; Forest and Rangeland Renewable Resources Act of 1978. These pieces of legislation and others reflected the environmental concerns of the people, including the rangelands.

Following the passage of NEPA, the BLM began preparation of an Environmental Impact Statement (EIS) covering rangeland management decisions and circulated a draft in March, 1973. In October the Natural Resources Defense Council (NRDC) filed suit in the U. S. District Court of the District of Columbia to require BLM to prepare individual site specific EIS's for grazing management decisions covered in allotment management plans. On December 30, 1974 the Federal Court ruled in favor of NRDC and directed the preparation of a subsequent agreement with BLM which required the preparation of 212 EIS's (now consolidated to 144) over a 13-year period ending on September 30, 1988 (501). The court ordered that each EIS must discuss "...in detail all livestock grazing activities and all reasonable alternatives thereto."

The new legislation, the court case, the public interest that produced both, and the foment of discussion produced by them, resulted in a symposium on Rangeland Policies for the Future (484) convened January 28-31, 1979 in Tucson by the U.S.D.A., U.S.D.I. and Council on Environmental Quality. Speakers were from various governmental agencies, user groups, professional societies and academia. A condensed version of the proceedings (485) was prepared. The summary of this "Sense of the Symposium" reads as follows.

"Approximately 320 participants contributed productively and with enthusiasm to successful completion of the Symposium on Rangeland Policies for the Future, Tucson, Arizona, January 28-31, 1979.

"The Sense of the Symposium is that rangelands of the U.S.A. are an important national resource of considerable and long-time importance. They are generally well-managed and in better condition than in the past, but still contain sizeable acreages of poor condition rangeland. With better management and improvement, this more than 800 million-acre resource can contribute more effectively to the national good. If all concerned interests work together in a cooperative manner, range can become a full partner in natural resource management.

"Technology is available for much of the job of improving conditions and applying sound rangeland management, yet the administrative and management process often constrains the job. Affecting the goal of achieving a national rangeland base in satisfactory condition with a community of economically-viable livestock producers, has been the attitude that rangeland is a step-child of natural resources and agricultural production. Insufficient funds for rangeland programs and not enough highly-qualified personnel also have limited progress. In addition, the economic problems of a cost-price squeeze directly affect the economic stability of the livestock producer and his ability to invest in range improvement.

"Accelerated application of existing range technology should increase the rate at which rangelands become fully productive for all goods and services. Intensification of research on improving rangeland for forage production, per se, and on inventory techniques should complement existing range research programs" (485).

7.4.1.2 Recent Policy Statements

In response to the symposium, statements of range policy or statements involving range policy have been released during 1979 and 1980 by the Secretary of Agriculture (502), the Bureau of Land Management (501), and Science and Education Administration (503). Certain alternatives for implementing policy are discussed in the RCA document by U.S.D.A. (383).

The U.S.D.A. national goals for range were (502):

1. Bring ranges fully into the structure and planning of American agriculture.
2. Improve productivity while protecting and enhancing the biological and physical integrity of range ecosystems.
3. Foster a permanent, increasingly productive range livestock industry.

4. Provide fundamental knowledge and improved technology for policy and management decisions for optimum use of all range resources.
5. Support and strengthen National and international cooperation designed to benefit ranges and their users.
6. Enhance conservation of range and water resources and maintenance of environmental quality.

The items considered in policy were:

1. Cooperation and coordination with other agencies.
2. Inventories, assessments and appraisals of the Nation's range resources.
3. Range research program.
4. Educational and technology transfer programs to bring various uses into balance on ranges and into balance with other aspects of agriculture.
5. Technical and financial assistance.
6. National Forest System.
7. Professional range-educated work force.
8. Equal opportunity, occupational safety and health element in technology development.

The Secretary directed that within one year (by October 25, 1980) each agency of the department will bring its policies and program direction into compliance with this memorandum. To implement this policy statement a Departmental Committee on Range was established including representatives from nine agencies. The document recognizes range as a kind of land producing many products of value to man.

Likewise, the BLM regards range as an ecosystem producing many products (501). BLM policy is determined by the Federal Land Policy and Management Act of 1976 and is to "manage efficiently the basic resources of the public rangelands to improve and maintain their productive capability to serve the full range of natural, social, economic, and environmental needs. In carrying out this policy, the Bureau will be guided by the management requirements for protecting and improving the basic soil, water and vegetation resources; the importance of maintaining a stable and sustainable livestock industry; the need to protect and improve habitat for fish and wildlife resources; the need to maintain viable herds of wild horses and burros; and many other public benefits that these resources are capable of providing."

7.4.2 Major Problems of Rangelands in Relation to Policy

7.4.2.1 General

The problems of rangeland deterioration, the factors predisposing toward deterioration, and the technology for improvement were discussed in section 5. The problems of the ranch business and land conversions were discussed in section 6. The major problems that interact with federal range policy are judged to be the following.

7.4.2.2 Overgrazing

Continued overstocking, leading to overutilization, results in overgrazing which is measured by range condition (33). Ranges in low range condition which are also overutilized are more susceptible to erosion and desertification (broadly defined) with a reduction in most of the products and values of the land, including net returns to the owner. The hazards of overgrazing vary with different range sites. Areas in which long-lived woody plants invade or increase with deterioration require plant control for restoration of the ecosystem with flow of products and uses of which it is capable. Generally, those range sites which form a shortgrass sod with deterioration are less susceptible to erosion than those that have more bare ground exposed, etc. Reasons for overutilization and overgrazing were discussed in section 5.

7.4.2.3 Below-Optimum Production

On private lands, optimum production implies high, sustained production of a balance of various products and uses that yield a profit to the operator. When production is lowered, needed products are not made available, net ranch income is reduced and the prosperity of communities in the ranching area and the nation are reduced. Gray (448) states that "the socioeconomic impacts of improving rangelands should be measured in terms of multipliers--output, income and employment. Type I output multipliers for the range livestock industry in the Southwest average about 1.8 to 2.0, while a few reports indicate that Type I income multipliers are 2.5 to 3.0. That is, for every $1.00 of output generated in the range livestock industry, the local economy experiences an increase of $1.80 to $2.00 of economic activity; or for every $1.00 of income generated by the range livestock industry, the local economy experiences an increase of $2.50 to $3.00 in total household incomes."

Methods for improving rangeland were discussed in section 5, potential uses of rangelands were discussed in section 4 and some possibilities for increasing net ranch income were explored in section 6. Failure to fully develop the optimum productivity potential and the optimum balance of products represents a socioeconomic loss to the operator, the local community, the region, the nation, and the world.

7.4.2.4 Cultivation of Land That Should be Rangeland

The problem of converting class IV, VI and VII land to cropland, primarily for wheat production, the interacting factors that caused this land conversion and the problems of changing back were discussed in section 6.

7.4.2.5 Impacts of Mineral Development

The area expected to be impacted by strip-mining of coal was discussed in section 6. Other areas will be affected by the development of uranium, gas and oil as well as non-energy minerals. The Surface Mining and Reclamation Act of 1977 minimizes the damage from strip mining by requiring that the land be returned to its former productivity and requiring that the site be monitored for 10 years in the semi-arid region. Nevertheless there will be severe disruption initially during development and restoration. In addition to damage to the resource is the disruption of ranch businesses and the socioeconomic impact of development on community services. Small communities are being changed into boom towns with inflated populations, inadequate housing, schools, etc. While local people may benefit financially, the boom is not something which they desired. If local groundwater supplies (from the Madison formation) are used to transport the coal through a slurry pipeline, the effect on the water supply for ranches, rural communities and towns may be disastrous. Other effects of transmission (railroads, pipelines, power lines) and prospecting disturbance make the impact of mining complex and extensive in development areas.

7.4.2.6 Supply of Professional Range-Educated Personnel

People with high potential, educated for the management of range ecosystems for all the products and uses which these ecosystems can supply are needed in the public and the private sectors as land managers, advisory scientists, educators (at all levels) and administrators.

7.4.3 Philosophy of Government

7.4.3.1 The Traditional Philosophy

The traditional philosophy, dating back to the founding fathers is that the government derives its powers from the people and has only those powers specifically delegated to it by the people. Further, the people should require the government to do only those things which the people cannot do for themselves. With this philosophy, the government has a responsibility for rangeland research and education and for technical and financial assistance to initiate range improvement practices needed to benefit society (and usually the private landowner as well), but which are not economical for the operator, because of high capital requirements, time discounts, low or negative rates of return on investment. The remarks of the CAST Task Force (500) are pertinent for consideration of the problem of time discounting. "The task force was much concerned with the truly long-run aspects of soil and water conservation. If we apply a time discounting procedure, then results beyond about 50 years have no significant effect on present decisions. Society obviously has a time horizon well beyond 50 years; we should be concerned with the future of our descendants. Yet choosing programs without consideration for timing of results can be disastrous too; we do live in the present and near future, and we must take actions for our well-being in that near future. It was the considered judgment of the task force that economists and other social scientists have not really solved the issue of the time discount; the typical interest-rate discounting process tries to assume away the problem in a manner that is not acceptable to the total public. We offer no solution, but we felt an obligation to call attention to the problem....The task force agrees that soil and water conservation is often relatively unprofitable, or has a low rate of return, to the farmer in the short run. Other uses of his capital, his managerial talent, his labor, and his land often seem more rewarding--to him, and to his banker."

Technical and financial assistance could be used to persuade landowners to manage for game habitat, to preserve wetlands, or to make other management decisions which would not be economical for him to do without such assistance and which are valuable to society. The voluntary programs of the past largely reflect this philosophy of government.

The RCA Environmental Impact Statement of 1980 (389) presumably prepared with the USDA Statement of Range Policy (502) in hand, compares seven alternative strategies for conservation program development. These seven were 1) redirecting present conservation programs, 2) cross compliance between USDA programs, 3) regional resource project approach, 4) state leadership, 5) regulatory emphasis, 6) conservation performance bonus, and 7) natural resource contracts. Alternatives 3 and 4 relate to increased state and regional (rather than national) control, but do not relate directly to the philosophy of government. Alternatives 1, 6, and 7 appear consistent with the traditional philosophy of government in which the concerns of society are expressed in terms of education and financial incentives. Participation is completely voluntary in 1 and 6. While participation is voluntary in 7, the contract once made is legally binding. In the case of alternatives 2 and 5 a different philosophy seems to be required.

7.4.3.2 The Social Democratic Philosophy

In this philosophy the people demand more from the government (security, protection, prosperity, health, etc.) and delegate more authority to it in popular legislation. Experts in the executive branch develop policies and directives based on the legislation that extends the regulatory power of government into almost all facets of human life. On the basis of social good, mandatory regulations proliferate and individual liberty is reduced. Alternatives 2 and 5 seem to be based on this philosophy. "Cross compliance between USDA programs" (alternative 2) means that a rancher or farmer could not participate in one program without meeting the requirements of all programs. Thus, in order to participate in commodity support programs, crop insurance and loan programs, the operator would have to comply with soil and water conservation standards, etc. (389). Thus for financial survival, the operator may be forced into cross compliance whether he wishes to be or not.

Likewise, "regulatory emphasis" (alternative 5) means that various standards and regulations would be established by the USDA and technical assistance and financial benefits provided. The land owner would have to certify his compliance, subject to spot checks by the government. Failure to comply would mean the land owner would have to reimburse the government for the benefits supplied to him. While not envisioned now, penalties could be enacted later as has been done in connection with other regulations.

7.4.3.3 Comparison

Farmers have a long history of demand for commodity price supports and government services. In general Great Plains ranchers have remainly fiercely independent and have demanded that government stay out of their business. Most of these people support the traditional philosophy of government and, in general, have accepted technical assistance, cost-sharing, and drought-disaster relief. However, some have opposed these measures, also. Many of them would prefer state or regional, rather than federal control. They can be expected to fiercely resist any hint of compulsory measures.

7.4.4 Needed Changes in Policies or Directives

7.4.4.1 Equality of Rangeland With Cropland and Forestland

The range policy statements of the USDA and the BLM provide an adequate framework for federal activities and are great improvements over previous policies. It is too soon to evaluate action planned under these policy statements. However, some discussion of problems is needed.

The new USDA range policy statement implicitly recognizes range as a kind of land with many products and uses and the first goal is bring range into the structure and planning of American agriculture. Yet in the new RPA document (226), range management on the National Forest System is defined as the management of forage for livestock grazing. Furthermore, the RCA for 1980 (Draft) (383) was sent to a listing of national organizations two pages long, but, the Society for Range Management was not on the list. The organization and work of SEA-Agricultural Research, indeed the entire Department of Agriculture, is on a commodity basis rather than an ecosystem basis. Many changes will have to be made to make rangelands an equal with cropland and forestland in the USDA.

7.4.4.2 Organization and Personnel

As indicated at several places in this report, there is a very great need for range-educated people in all positions that involve rangelands. People with thorough education and background in rangelands should be recruited for these jobs. Once on the job they should have frequent training sessions, workshops, and educational leaves for further schooling in order to maintain and improve professional skills. Those employees without the needed professional education should be shifted to other jobs or be given educational leaves for professional range education. These employees, in every sense of the word, should be dedicated professionals, devoted to a goal of excellence. They should be marked by an attitude of pride in the particular service in which they are employed.

Furthermore, it is our opinion and that of many others (447, for example) that reorganization of many agencies is needed to put a higher proportion of the workers in the field rather than in various administrative jobs. In addition, there should be opportunities for field personnel to advance in salary, grade, and professional standing without shifting to administrative jobs.

With relation to public land managers, these decision-makers must be insulated from political pressures and be free to make wise decisions based on sound data, ecological wisdom and insight, using good decision-making tools with advice and counsel from capable staff and advisory groups. These decisions, of course, must be in accordance with legislation and agency policy. However, the decision-maker must not be afraid of losing his job or hurting his chances for professional advancement by making unpopular decisions.

7.4.4.3 Data Base

The first nation-wide assessment of range condition was published in 1936 and was largely descriptive (378). The next major national inventory was published in 1969 as part of the report of the Public Land Law Review Commission (504). During the '70s the USDA 1971 Inventory of Soil and Conservation Needs was published (505) and in 1972 the Forest-Range Environmental Study was published (225), drawing heavily on the Conservation Needs Inventory. In response to the Forest and Rangeland Resources Planning Act of 1974 the Forest Service prepared an RPA report for 1975 (382) and for 1980 (226). In response to the Soil and Water Conservation Resources Act of 1977, the U.S.D.A. prepared an RCA appraisal report for 1980 (383, 389). The computerized RPA data base has been described in a Forest Service document (420). These documents provide the best inventory of the rangelands of the nation and their uses which has ever been prepared. However, the data, often, have been subjective evaluations and have often been taken and reported in different forms by different agencies (486). These deficiencies are being worked on. There is a strong effort toward coordination among agencies, development of standard terminology (488) and improved methodology. At the present time we are a long way from sampling attributes of rangeland with the precision needed for management, especially on the public lands, but also on the private lands (447).

Adequate sampling and statistical evaluation will require new methods, probably involving remote sensing, using the LandSat system supplemented with airborne sensors and ground truth determination on benchmark areas in a double sampling design (see section 5). More funds and manpower with special skills will be needed. Not only sampling, but data summarization and publication should be done by ecological grouping, rather than, or in addition to, state boundaries and political subdivisions.

7.4.4.4 Planning and Administration of Public Lands

Wise planning and management of the public lands requires competent range-educated professionals using good decision-making tools with a good data base, and with sound advice from a staff of professionals with expertise in various uses of rangelands, but with an understanding of range ecosystems as well. These decisions must be made in accordance with legislation and agency policy with inputs from constituted advisory groups, but the decision-maker must not be subject to political pressure.

Rangeland is an ecosystem producing many products, including forage which can be used by domestic livestock. However, range management is not the management of forage for livestock grazing only, but the management of the range ecosystem for the optimum balance of products and uses which it can supply. As noted in section 4, these uses are usually complementary, and only rarely, directly competitive. As noted in sections 5 and 6 and by other scientists (432), livestock grazing is complementary to other uses and can be used to modify the ecosystem for increased values for other uses.

The cost of EIS preparation as required of the BLM in the 1974 court decision (501) far exceeds any value that they may have. The goals of society can be served in better ways than this. NEPA may need to be amended to prevent extensive wastage of resources in this effort.

The series of workshops which have been arranged at BLM's request by the Committee on Developing Alternative Rangeland Management Strategies of the Board on Agriculture and Renewable Resources of the National Academy of Sciences should provide valuable recommendations for management of the public lands. These reports should begin to appear in July, 1981 with the Forage Allocation Workshop Report coming out first.

7.4.4.5 Education, Technical and Financial Assistance

These program areas have been quite effective in the past. However, education and technical assistance could be made more effective by increasing the number and the professional capability of range-educated people in the field, making more use of ecosystem concepts and systems analysis procedures, and using more cost-returns data in working with land owners.

Long-term cost-sharing programs, with contracts and follow-up, more effectively assist the operator than short-term aid. The most important element is personal contact with a competent range professional over a long period of time.

Education, technical and financial assistance should be used to encourage wise management of the rangelands, including optimization of net ranch income, development of diversity, minimization of fossil fuel use and meeting the goals of society which it is not economical for the rancher to provide. However, fiscal responsibility is needed. Programs which are not economical should not be advocated unless they are important for the long-term goals of society. Generally, rangelands are lands with limitations on production due to climate, soil or other factors. Therefore, "The range manager is limited to low-cost measures, yet the changes he needs to bring about are often great. This requires that he use 'high-leverage' methods that cost little but have a great effect" (506).

High interest rates and restricted availability of capital are hurting ranchers very badly. There is urgent need for loans at low interest rates with flexible repayment schedules. However, care must be exercised so that financial aid from the government is not used to maintain a poor operator in the ranching business. Possibly, a history of improving net worth should be used as one of the criteria of loan assistance.

Loans to assist young people to get into the ranching business are needed but caution must be exercised. The government does not do a man a favor to enable him to borrow money to buy land that is so expensive that there is no way to pay for it from the proceeds of the land.

7.4.4.6 Cultivated Land Unsuitable for Crop Production

As noted in section 6, considerable areas of rangeland in the Great Plains, classified as unsuitable for cultivation in land capability classes IV, V, VI and VII, were plowed and cropped to wheat during the '70s. Most of these erosion-prone lands were also in the semi-arid region of the Great Plains. In the opinion of the authors, the break-out was motivated by the economic factors, noted in section 6, of relatively low cattle prices, relatively high wheat prices, and relatively low costs of fuel, machinery, fertilizer and herbicides early in the period. The variable nature of precipitation around the lower limit for crop production made the possibilities of success look more interesting. Some plowed the range and expected to sell the land as cropland, but most simply planned to go into the wheat business. There may have been a perception on the part of these operators that government programs would take most of the risk out of the venture. Export agreements and price supports argued for relatively favorable prices. Crop insurance, low-cost loans, disaster programs and other portions of the farm program provided some security against a possibly uncooperative climate. They may have reasoned that if worst came to worst, the government would provide a liberal cost-share for revegetation to introduced pastures which might be more productive than native range in low range condition. Thus, federal farm policies designed to stabilize agriculture may have contributed to the break-up of a large amount of native range on land which is not suited for cultivation, and so, may have contributed to wind and water erosion.

Government policies that are designed to stimulate grain production are likely to encourage the cultivation of land that is unsuited for crop production. This is especially true in the wetter phase of the climatic cycle, especially when economic factors favor the products of cropland more than rangeland.

Failure to understand the complex nature of the range ecosystem, the cost of reseeding to native species, and the impossibility of restoring the native prairie in a short period of time are also factors favoring break-out.

Most of these lands should be returned to native range, using local ecotypes of native plants from similar soils. However, such seed supplies are not adequate to seed large acreages. Furthermore, the variable nature of the demand makes it unprofitable for seed dealers to harvest local ecotypes and stockpile seed in the expectation of future sales. Furthermore, the high cost of range seeding, including both direct costs (seedbed preparation, seed, drilling, weed control and pest control) and indirect costs (production lost during the establishment period, taxes, interest on investment, maintenance and depreciation of fencing, and risk of stand failure) may exceed the productive value of the land.

Clearly, it is in the interest of society to assist in developing seed sources of ecotypes of native range plants and in reestablishing range vegetation on these lands. Further, it is in the interest of society to provide education and technical and financial assistance to provide an incentive for them to be managed as productive rangeland on a sustained basis.

7.4.4.7 Education of the General Public

The need for public education about rangelands at all levels of society was discussed in section 7.2. Policies to implement an educational program for the elementary and secondary schools will have to be developed at the local and state level. Impetus, perhaps, can be provided through the Society for Range Management and the Extension Service. The U. S. Department of Education may be able to make some materials available if there are qualified personnel to prepare them. The Extension Service and the Society for Range

Management should also provide leadership in the education of the general public about rangelands through articles in general magazines and newspapers, television programs, advertisements, etc.

This matter is particularly urgent in order for the general public to appreciate rangelands and be concerned about them and about those who manage them. Such knowledge and appreciation is needed for people to understand that range research, education and management is important to them.

7.4.4.8 Matters Relating to Fiscal and Monetary Policy

There is no question that all aspects relating to rangelands have been underfunded in relation to other activities at the local, state and federal level. There is a need for more and better-trained professional workers, for better funding of existing programs, and for adequate funding of new projects. Yet, government at all levels has grown almost beyond imagination. The social democratic philosophy of government (section 7.4.3.2) has prevailed and the size and cost of government has continued to grow. Cumulative federal deficits with a one-year lag were almost perfectly correlated (r = 0.99) with increases in money supply and subsequent increases in prices (507). A large portion of the American public appears to be convinced that the deficit spending, oppressive taxation and regulation of big government are a major cause of inflation and of the economic ills of the country. The Republican party has just won an impressive electoral victory with a platform and campaign rhetoric calling for less government and for less expensive government. This is basically a call for a return to a philosophy of government more like the traditional one described in 7.4.3.1. However, the margin of the popular was not large. The number of Americans favoring the social democratic philosophy is very large, probably more than half of all citizens. Spending cuts are likely to be made in all areas of government, while demand for governmental services will increase. In the resulting competition, the needs of rangelands are likely to be passed by. This is especially true since the vast majority of those associated with the range livestock industry and indeed with the entire range management profession hold views closer to the traditional philosophy of government than the average of the population.

Certainly, the nation should be frugal. The powers and costs of government should be held in check, the budget should be balanced, inflation controlled; savings, investments, innovation and productivity should be increased and the dignity of the individual and the power of the American dream restored. But, in the inevitable competition, rangelands should receive attention befitting their importance.

7.4.4.9 Federal versus Regional or State Control

This report has been concerned primarily with federal policies and programs affecting rangelands, however, state activities are becoming more important. For example, a Rangeland Improvement Loan Program was funded by the Montana state legislature for $300,000 for the fiscal years 1979 and 1980. Application has been made for $500,000 for the next biennium. These are loans made with no interest and approved first by the local Soil and Water Conservation District with final approval made by the Executive Committee of the Montana Rangeland Resources Programs (P. V. Jackson, personal communication).

The Montana Rangeland Resources Program has been quite successful. The Old West Regional Range Program (OWRRP) was modeled, in part, after the Montana Program. The OWRRP was also very successful (482). The Old West Regional Commission is composed of the governors of Montana, Wyoming, North Dakota, South Dakota and Nebraska and is one of eight such commissions set up by the

Public Works and Economic Development Act of 1965. The Commissions are neither federal nor state agencies, but an equal partnership between the two. Federal funds apportioned to the regional commissions are used for various activities for regional development. The Society for Range Management made application to the Old West Regional Commission and received a grant of $540,000 for a two-year period beginning in March, 1975 and subsequently extended for two years with additional funding. The OWRRP was structured to fill critical gaps in range management educational efforts and initiate action toward meeting long-range goals for rangelands. Programs such as the Montana Rangeland Resources Program and the OWRRP have better local support and closer local supervision than some of the federal programs. However, the educational, technical and financial assistance activities of the Soil Conservation Service are closely tied to local Soil Conservation Districts and achieve a very high level of local support.

The incoming Reagan administration in campaign rhetoric indicated a preference for reducing the size of the federal government by making block grants to the states and turning some programs over to them. The RCA Program Report and Environmental Impact Statement (389) listed "regional resource project approach" and "state leadership" as two of seven alternative strategies for program development. In these two strategies federal leadership was retained in some areas to insure coordination and the fulfillment of national priorities and to determine funding needs, while other areas were transferred to state leadership or to the regional program. If the states or regions were ready to assume leadership, such a procedure would place supervision closer to the people on the land.

7.5 Range Research

In 1967, McKell addressed the Society for Range Management in Seattle presenting a list of nine important research areas for the next 20 years (509). In the same year the Agricultural Research Service published challenges in forage and range research (508) and the Range and Livestock Management Committee of the Great Plains Agricultural Council presented an 11 page mimeographed summary of Range and Livestock Management Problems of the Great Plains (516), compiled from lists of problems submitted by American National Cattlemen's Association, National Woolgrower's Association, American Society of Range Management and from state and federal agency summaries prepared by members of the committee. The compilation was made by the Chairman, J. K. Lewis, in an ecosystem framework. In 1969 this committee forwarded a report to the Great Plains Agricultural Council listing the three most important problem areas in forages and feed production in the Great Plains (521). Following an introductory statement the following list was submitted:

"1. The effects of different grazing systems (including intensity, season of use, kinds of grazing animals and sequence of grazing) when applied on different range sites in different range condition classes, on all phases of the range ecosystem and on the economics of ranch operations.

2. The optimum kinds and combinations of different land uses (range, tame pasture, and crop) for the production of various goods and services (such as livestock grazing, hay, wildlife habitat, watershed values, pollution control and recreation) over long time periods, encompassing both wet and dry phases of the climatic cycle on different range sites for public lands and for different kinds of ranching operations.

3. The use of fertilizers and legumes on different kinds of grazing land under different grazing systems on all phases of range and pasture ecosystems and on the economics of ranch operations."

These reports were regional in scope and were not presented in the framework of the Long Range Study of the U.S.D.A.

In 1968 a Joint Task Force appointed by the Secretary of Agriculture submitted a report on research needs in forage, range, and pasture through 1977 (510), within the framework of the Long Range Study. Research problem areas (RPAs) were listed with the problem developed under the following headings: Situation, Objective, Research Approaches, Character of Potential Benefits and Recommended Research Effort. Their recommendations are summarized in Table 60.

Future research by the Forest Service was outlined in 1970 (375). Various compilations of range research needs were made on a national (511, 514, 515, 446, 512, 513) and on a regional basis (517, 518, 519, 520) during the '70s. In spite of the emphasis on research needs in this vital area, in 1977, the National Planning Committee of the Agricultural Research Policy Advisory Committee (446) commented as follows,

"In the eight year interval from 1967 to 1975, the emphasis devoted to range and forage research for red meat production declined from 674 to 639 SY's. Although there was either a modest increase or essentially no change in many RPA's (Research Problem Areas), there was a substantial decline in the RPA's that have a direct input to improving range and forage resources. Thus, support for RPA 112, Improvement of Range Resources, decreased from 139.4 to 92.0; RPA 307, Improve Biological Efficiency of Field Crops, from 249.2 to 204.3; and RPA 313, Production Management Systems for Livestock, from 9.1 to 4.9 SY's."

This committee (446) presented researchable problems in the range and forage area in five groups with 44 researchable areas grouped into RPAs. The groups and numbers of problems were A. Improving Grasses and Legumes for Range and Forage Use (8 areas), B. Improving Management of Range and Forage Crops

Table 60. Summary of Inventory and Recommendations (510)

Research problem area	1966[1] Inventory	1972 JC recom.[2]			1972 TF recom.	1977 JC recom.[2]			1977 TF recom.
		SAES	USDA	TOTAL		SAES	USDA	TOTAL	
110 Appraisal of forest and range resources					23				
112 Range management	154	77	88	165	181	93	111	204	
Subtotal - Range	(154)	(77)	(88)	(165)	(204)	(93)	(111)	(204)	(266)
207 Control of insect pests	57	50	27	77	79	64	34	98	98
208 Control of diseases	31	34	16	50	50	49	21	70	70
209 Control of weeds and other hazards	17	15	11	26	33	18	13	31	38
Subtotal - Protection	(105)	(99)	(54)	(154)	(162)	(131)	(68)	(199)	(206)
307 Biological efficiency	277	254	57	311	340	327	78	405	438
308 Mechanization	19	13	9	22	25	14	10	24	33
309 Systems analysis	2				7				9
405 Consumer acceptability	3	3	0	3	3	3	0	3	3
Subtotal - Production	(301)	(270)	(66)	(336)	(375)	(344)	(88)	(432)	(483)
406 Food products	3/	3/	0	3/	3/	3/	0	3/	6
407 Feed and non-food products	12	6	9	15	25	8	13	21	32
Subtotal - Utilization	(12)	(6)	(9)	(15)	(28)	(8)	(13)	(21)	(38)
408 Market quality	6	1	7	8	8	1	8	9	9
501 Grades and standards	2	2	3/	2	4	2	3/	2	5
504 Market efficiency	2	2	3/	2	4	2	3/	2	6
601 Foreign markets					2				3
Subtotal - Marketing	(10)	(5)	(7)	(12)	(18)	(5)	(8)	(13)	(23)
GRAND TOTAL	582	457	224	681	787	581	288	869	1016

---

[1] 1966 Base (Volume 1, table 1, "An Inventory of Agricultural Research").

[2] Projected increases from joint committee of State and USDA Research Administrators, Chicago, Illinois, July 1967.

[3] Less than one-half scientist man-year.

(10 areas), C. Reducing Limiting Facotrs in Range and Forage Production (8 areas), D. Improving Management of Livestock on Range and Forage (9 areas), E. Reducing Limiting Factors in Range- and Forage-based Livestock Production Systems (11 areas). Their recommendations for an increased research effort is shown in Table 61. They further comment "There is a critical need to provide more adequate funding for maintaining the effectiveness of current range-forage-livestock research programs. Range and forage technology is estimated to be as much as 25 years behind that of cereal crops because of inadequate funding. This deficiency in technology is, by itself, strong justification to increase funding in order to optimize all facets of agricultural production."

In 1976, a Joint Task Force of the Great Plains Agricultural Council composed of research scientists from the State Agricultural Experiment Stations and the U.S.D.A. in the ten Great Plains states submitted a compilation of range research needs for the Great Plains (517), arranged by 17 research problem areas. For each RPA, the following sections are presented: Situation, Objectives, Researchable Problems and Potential Benefits. A listing of the researchable areas with recommended staff requirements are shown in Table 62.

In 1978 members of the range sub-task force of a Western Regional Task Force (which produced a report entitled "Range, Wildlife Habitat and Fisheries: Research Needs and Priorities") published an article in the Journal of Range Management entitled "Research Needs on Western Rangelands" (512). This group divided research into five areas with discussion and objectives for each and a determination of priority (Table 63).

In 1977 Agricultural Research, Science and Education Administration initiated a review of range research. The first phase, now in manuscript (G. E. Carlson, personal communication), assessed range research and identified

Table 61. Summary of 1967, 1975, and Future Recommended Allocation of Scientist Year (SY's) to Range and Forage Research by Research Problem Areas (RPA's) (446)

	Research Problem Area		Recommended		
No.	Name	1967	1975	1980	1985
102 1/	Soil, Plant, Water, Nutrient Relationships	22.0	19.2	21.2	32
107	Watershed Protection and Management	*	2.0	3.0	4
110	Appraisal of Forest and Range Resources	6.0	5.4	5.4	8
112	Improvement of Range Resources	189.4	92.0	103.0	125
203	Prevention and Control of Forest and Range Fires	*	1.8	1.8	3
207 2/	Control of Insects Affecting Field Crops and Range	50.7	59.1	65.1	75
208 2/	Control of Diseases of Field Crops & Range	35.7	38.9	41.9	50
209 2/	Control of Weeds of Field Crops & Range	16.4	33.0	37.0	50
212 3/	Control of Internal Parasites of Livestock	41.2	23.7	24.7	29
213 4/	Protect Livestock from Toxic Chemicals, Poisonous Plants, and Other Hazards	6.3	14.4	15.4	17
214	Protection of Plants and Animals from Pollution	0.4	1.5	1.5	3
307 2/	Improve Biological Efficiency of Field Crops	249.2	204.3	218.3	260
308 2/	Mechanization of Production of Field Crops	16.1	10.9	12.9	20
309 2/	Production Management Systems for Field Crops	2.8	12.0	13.0	15
310 5/	Reproductive Performance of Livestock	24.6	41.6	45.6	55
311 6/	Improve Biological Efficiency of Livestock	26.1	27.3	30.3	35
313 6/	Production Management Systems for Livestock	9.1	4.9	11.9	22
405	Production of Field Crops with Improved Acceptability	2.9	15.3	16.3	20
407	New and Improved Products from Field Crops	11.3	19.2	20.2	22
408, 501, 503, 506, 507 509, 604, 701, 702, 708, 808, 901, 903	Other Range and Forage Related	13.8	12.5	14.5	18
	Totals	674.0	639.0	703.0	863.0

1/ 10 percent of total research estimated to be range and forage related.

2/ 10 percent of research conducted on corn included in these RPA's as an estimate of corn used for silage.

3/ 100 percent of beef and sheep research included.

4/ 50 percent of beef and sheep research included.

5/ 50 percent of beef and sheep and 10 percent of dairy cattle research included.

6/ 10 percent of beef, sheep, and dairy cattle research included as an estimate of that related to range and forage for meat production.

*Not available.

Table 62. Summary Table Showing Allocation of Scientist Years (SY's) to Research Problem Areas (RPA's) Under Different Levels of Funding (517)

		SY Allocation			
			With 10% increase	To solve in 10 years	
RPA	Short title	1975		Committee estimates	State estimates 1/
102R	Soil, Plant, Water & Animal Relations	24.6	26.0	50.0	47.0
104R	Multiple Uses of Range Resources	8.1	8.0	10.0	21.0
110R	Appraisal of Range Resources	6.5	7.0	15.0	7.0
112R	Improvement of Range Resources	20.1	25.0	37.0	38.0
207R	Management of Range Insects, Rodents & Predators	7.6	9.0	25.0	15.0
208R	Control of Plant Diseases & Nematodes	2.0	3.0	10.0	10.0
209R	Control of Weeds and Brush	17.1	20.0	30.0	32.0
213R	Protection from Toxins, Poison Plants & Pollutants	1.4	2.0	5.0	9.0
307R	Production Efficiency of Range Plants	16.3	20.0	30.0	38.0
308R	Engineering Developments	2.2	4.0	8.0	14.0
309R	Production Management Systems	14.4	16.0	24.0	32.0
311R	Production Efficiency of Range Animals	20.4	17.0	35.0	28.0
316R	Ranch Business Management	4.2	4.0	8.0	11.0
501R	Improvement of Grades & Standards	1.8	1.0	3.0	5.0
503R	Efficiency in Producing & Marketing	2.8	3.0	6.0	6.0
506R	Supply & Demand Analysis & Price Predictions	4.1	4.0	8.0	6.0
510R	Group Action & Market Power for Range Products	0.1	1.0	1.0	4.0
	TOTAL	153.7	170.0	325.0	323.0

1/ Summary of estimate by range scientists in each state.

Table 63. Problem Categories and Research Priorities for Western Ranges (512)

Problem category	Percent priority[1]	Rank[2]
I. Identification, Classification, and Inventory of Range Ecosystems	23	2
II. Dynamics of Individual Plants and Communities	27	1
III. Improvement of Rangelands for Increased Productivity	22	3
IV. Short and Long-term Grazing Impacts	16	4
V. Influence of Economic, Social and Political Constraints on Management of Range Resources	12	3

[1] The relative distribution of research resources to the problem category.

[2] The relative importance of each problem category. "We believe the research problems ranked 1 and 2 above need immediate attention."

research needs within SEA-AR in the 17 continguous western states. Subsequent reports will assess range research by the Forest Service, State Agricultural Experiment Stations and other colleges and universities. Problems were identified, interdisciplinary teams structured to deal with each, then priorities assigned and the requirement of scientist years estimated. A needed staff increase of 58% was projected.

Most of these studies suggest or state the urgency of additional scientist years for range research and additional funds to address range problems. These staff and funding increases, in general, have not materialized at the state or the federal level. In general the same research areas that were important a decade ago are still important problems. In many of the research needs summaries, little distinction is made between the research needs of ranges and of introduced pastures. In some reports there is heavy emphasis on an agronomic approach to the management of rangelands with costly inputs and intensive control of the ecosystem, although others have emphasized the importance of multiple-use management of ecosystems.

The International Biological Program sponsored research on terrestrial ecosystems on a world basis. In the United States an Analysis of Ecosystems Program supported projects in the grassland, deciduous forest, coniferous forest, tundra and desert biomes. Grassland studies were conducted in Canada and the United States in North America and at various locations on other continents. The Grassland Biome project in the United States was administered through Colorado State University with an intensive site near Nunn, Colorado on the Central Plains Experimental Range and a total of 10 comprehensive network sites, located in various grasslands. Comprehensive network sites (Fig. 11), located in the Great Plains region (as defined in this report) were at Dickinson, North Dakota, Cottonwood, South Dakota (near Philip) and Hays, Kansas in the Mixed Prairie (all in Plains grasslands) and at Osage near Foraker, Oklahoma in the True Prairie (Prairie). Results of these studies have appeared in a large series of technical reports and journal articles. Data have been synthesized in several volumes (398, 399, 400, 401) and several long articles (among them 402, 403). One book on the True Prairie ecosystem is in press (404), a summary volume on the North American grassland is partially completed and a synthesis volume of management applications is in preparation.

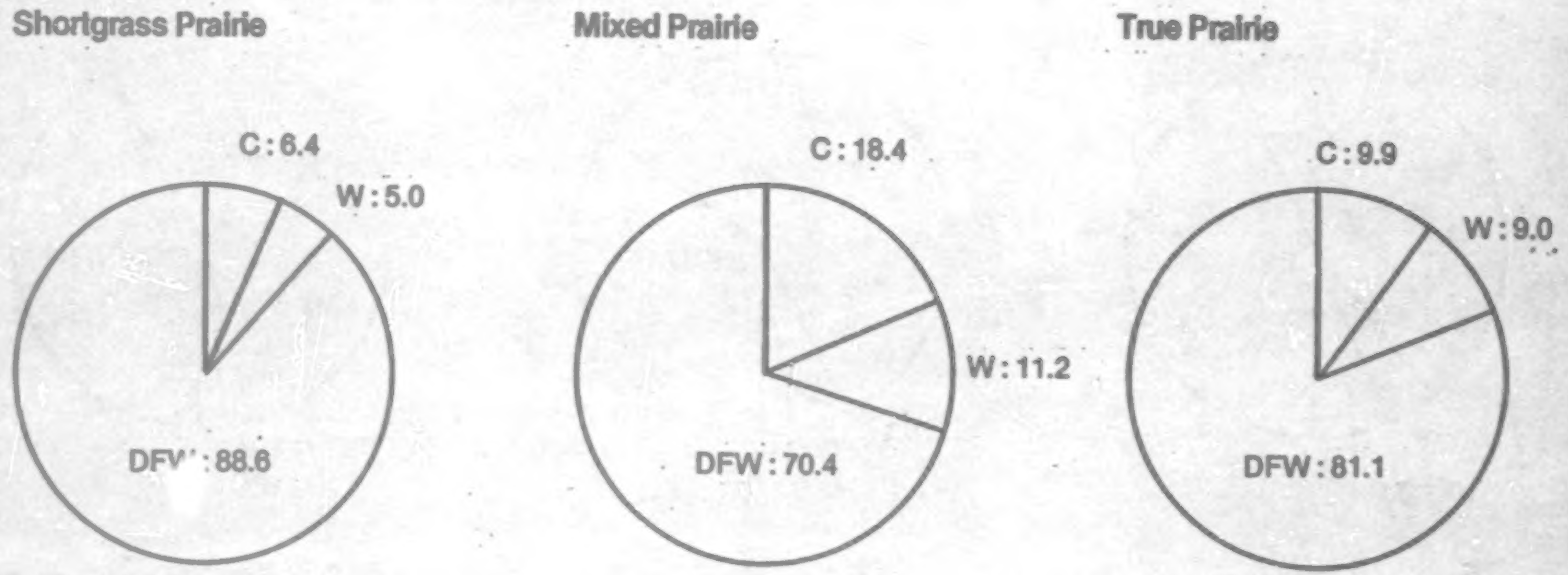
These studies have emphasized the importance of energy flow and nutrient cycling in grassland ecosystems and how these functions are affected by grazing disturbance. Especially surprising is the very large amount of the net primary production used directly by the detrital food web (Fig. 73), the very high percentage of herbivory that occurs below ground (Fig. 74), the relatively small percentage of the net primary produced consumed by livestock (Table 64), in comparison with nematodes (29).

These perspectives on energy flow in grassland ecosystems suggest that alternatives for improvement of rangelands can be grouped into those that 1) increase net primary production (NPP), 2) allocate more of the NPP above-ground within reach of grazing, 3) improve the efficiency of use, and 4) reduce competing herbivory (29). These categories are not mutually exclusive, some practices will act in more than one way. Relatively little is known about the influence of many common practices on pathways of energy flow. In 1976 a range research program for South Dakota State University was structured around a major objective of maximizing metabolizable energy intake of managed grazing animals on a sustained basis, without injury or large disturbance to the ecosystem, using an interdisciplinary team to study the effect of different manipulations on energy flow pathways (522). Only small parts of this proposed research has

Herbivory in Grasslands Without Large Grazers, 1972

(from Scott et al., in press)

Partitioning of Energy, percent NPP



Primary Production, Kcal / m²

NPP	3767	3591	5033
AG, p[illegible]	15.2	33.9	25.7

Figure 73. Net primary production and the partitioning of energy flow in three grasslands without large herbivores, 1972 (29).

Herbivory in Grasslands Without Large Grazers, 1972

(from Scott et al., in press)

Partitioning of Consumption and Wastage, percent

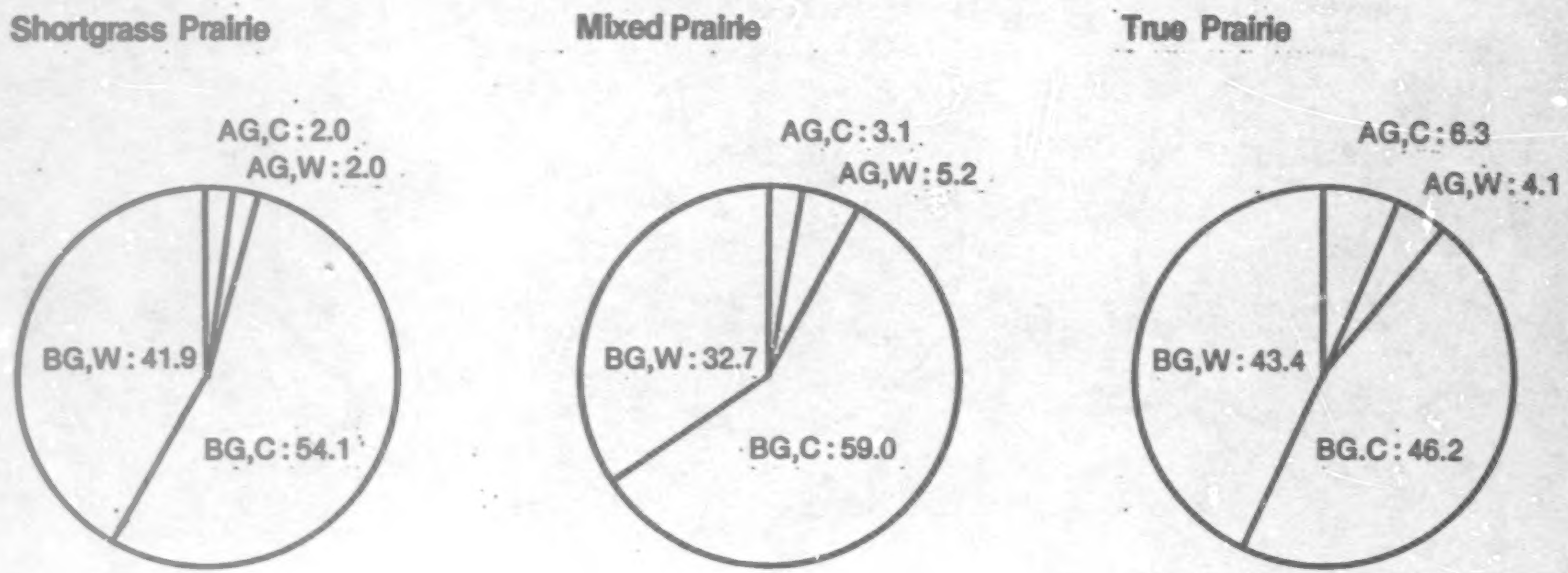


Figure 74. Partitioning of herbivore consumption and wastage in three grasslands without large herbivores, 1972 (29).

Table 64. Herbage Consumption and Wastage by Major Herbivores, Mixed Prairie, Cottonwood, South Dakota, 1972 (calculated from 42 by 29)

Subsystem and herbivore	Consumption and wastage, Kcal $m^{-2}yr^{-1}$		Total net primary production, %	
	Consumption	Consumption plus wastage	Consumption	Consumption plus wastage
Above-ground				
Cattle[1]	172	258	5	7
Sapfeeders[2]	25	74	1	2
Other	9	23	t	1
Below-ground				
Sapfeeders[2]	382	622	10	17
Other	245	351	6	9
Total	832	1328	22	36

[1] Cattle intakes and wastage were calculated from other data, assuming no reduction of other herbivores.

[2] Above-ground sapfeeders are mainly arthropods, especially scales. Below-ground sapfeeders are mainly nematodes.

initiated. Our evaluation is that top priority should be given to this approach in range research. When the effect of various manipulations of energy flow pathways are understood there is a high probability that the production of managed grazing animals can be doubled without using unduly expensive inputs.

Additional funding for additional scientist years and for increased equipment and operating expenses are urgently needed at the state and federal level. Passage of the Range Research bill introduced in both houses of the Congress in 1979 is needed. Money invested in ranch research can be extremely valuable for the future productivity and quality of the rangelands of the Great Plains, and the prosperity of individual ranchers, the region, the nation and the world.

8. GLOSSARY

Definitions are supplied by the authors or taken from the reference indicated by number (see Literature Cited).

ABOVE-GROUND STANDING CROP. See standing crop.

ADIABATIC COMPRESSION. The process by which air moving from a higher to a lower elevation is warmed.

ANIMAL-UNIT. Considered to be one mature (1000 lb.) cow or the equivalent based upon average daily forage consumption of 26 lb. dry matter per day. Abbr., A.U. (224).

ANIMAL-UNIT MONTH. The amount of feed or forage required by an animal-unit for one month. Abbr., A.U.M. (224).

ARID. Excessively dry. An arid climate according to Thornthwaite's 1948 classification (234) is one in which the moisture index ranges from -40 to -60, where

$$\text{Moisture Index} = \frac{(100\text{x water surplus}) - (60 \times \text{water deficit})}{\text{potential evapotranspiration}}$$

BIOTYPE. A group of individuals within a population occurring in nature, all with essentially the same tolerance ranges. A species usually consists of many biotypes. cf. ecotype (224).

BOTANICAL COMPOSITION. The proportion of the above-ground vegetation contributed by different plant species, expressed as percent cover or percent weight.

BRUSH. Woody half-shrubs, shrubs and trees that invade land on which they are not part of the potential natural (climax) plant community or occur in amounts significantly in excess of that which is natural to the site (383).

CANOPY VAPOR PRESSURE DEFICIT. The difference between the actual vapor pressure in the atmosphere in the canopy and the vapor pressure at saturation (489).

CENTRALLY-PLANNED COUNTRY. A country where management decisions are made by planners of the central government; a communist country.

CLAYPAN. A dense compact layer in the subsoil having a much higher clay content than the overlying material from which it is separated by a sharply defined boundary; formed by downward movement of clay or by synthesis of clay in place during soil formation. Claypans are usually hard when dry and plastic and sticky when wet. They usually impede the movement of water and air (224).

CLAYPAN COMPLEX. A soil mapping unit with a claypan soil taxonomic unit and one or more other taxonomic units so intermixed that it is impractical to separate them, but in which the claypan significantly limits the productivity potential of the complex.

CLIMAX. The final or stable biotic community in a successional series; it is self-perpetuating and in equilibrium with the physical habitat (488).

COMPLEMENTARY PASTURES. Full-seeded pastures composed of monocultures or simple mixtures of forage plants, such that a series of pastures provides a greater quality of better forage than any one alone, or than native range alone.

CONSTRAINTS. Limits or restrictions set on the solution space in an optimization model.

CONTINUOUS GRAZING. The grazing of a specific unit by livestock throughout a year or for that part of the year during which grazing is feasible. The term is not necessarily synonymous with yearlong grazing (224).

CONTOUR FURROW. A plowed or listed strip on a contour line for the purpose of water retention (224).

DEEP RIPPING. The mechanical penetration and shearing of the subsoil to disrupt compact layers to facilitate penetration of plant roots, water, organic matter, and nutrients. Often used with deferment to stimulate growth of rhizomatous native grasses.

DEFERMENT (OF GRAZING). Delay or discontinuance of livestock grazing on an area for an adequate period of time to provide for plant reproduction, establishment of new plants, or restoration of vigor of existing plants (224).

DENSITY. (1) The number of individuals per unit area. (2) Refers to the relative closeness of individuals to one another (224).

DESERTIFICATION (DESERT ENCROACHMENT). Expansion of deserts into regions that are usually considered as rangelands; deterioration of rangeland to desert; decrease in precipitation due to increase in the reflectivity of rangeland surfaces caused by overgrazing; broadly, increased aridity due to overgrazing or other kinds of mismanagement (493, 494).

DETERIORATED RANGE. Range on which present vegetation and soil conditions represent a significant departure from natural potential. Syn., degenerated range (224).

DIVERSITY, SPECIES. Heterogeneity of communities, represented by richness or number of species and evenness or patterning of communities; quantified by a large number of diversity indices.

DROUGHT. A deficiency of precipitation severe enough to cause alteration of usual management procedures; deficiency of precipitation causing extensive reduction in net primary production and usually changes in botanical composition.

ECOLOGICAL DIVERSITY. See diversity.

ECOSYSTEM. An ecological system resulting from the integration of all of the living and the non-living factors of the environment.

ECOTYPE. A locally adapted population of a species which has a distinctive limit of tolerance to environmental factors. cf. biotype (224).

ENERGY FLOW. The transfer of photosynthetically fixed solar energy through the ecosystem.

FORAGE. Browse and herbage which is available and may provide food for grazing animals or be harvested for feeding (488).

FORAGE PRODUCTION. The total quantity of forage produced per acre in a year or in a specified period of time.

FORAGE UTILIZATION (UTILIZATION OR USE). The proportion of current year's forage production that is consumed or destroyed by grazing animals. May refer either to a single species or to the vegetation as a whole. Syn., degree of use (224).

GOAL PROGRAMMING. A mathematical approach to optimization. A series of goals are established which can be expressed as mathematical equations. However, due to constraints on the original problem, not all the goals can be met simultaneously. It is necessary to allow positive and negative slack within these goals equations. This slack is allocated to "slack variables," which are combined with the goals to form a linear equation to be minimized or maximized and a series of accompanying constraint equations. This system of equations is then solved by standard linear programming techniques (after Goodman, 1974) (490).

GRAZING SYSTEM. A specialization of grazing management which defines systematically recurring periods of grazing and non-use for two or more pastures or management units (adapted from 224).

HERBAGE. The above-ground material of any herbaceous plant (488).

HIGH PERFORMANCE GRAZING SYSTEM. A system in which grazing is managed to stimulate plant growth rate and provide moderate utilization of preferred forage. The system involves large numbers of pastures grazed with high concentrations of animals for very short times (39).

HUMID. Excessively wet. A humid climate according to Thornthwaite's 1948 classification (234) is one in which the moisture index is between 20 and 100, where

$$\text{Moisture index} = \frac{(100 \times \text{water surplus}) - (60 \times \text{water deficit})}{\text{potential evapotranspiration}}$$

WATER INTAKE (WATER INFILTRATION). The downward entry of water into the soil (491).

INTERCEPTION (PRECIPITATION INTERCEPTION). The stopping, interrupting and temporary holding of precipitation in any form by a vegetative canopy or vegetation residue (491).

INTRODUCED PASTURES. Lands full-seeded to monocultures or simple mixtures of introduced forage plants, which usually have been selected for yield and/or forage quality, and which usually require intensive management inputs to maintain high productivity.

LAND CAPABILITY. The suitability of land for use without permanent damage. Land capability, as ordinarily used in the United States, is an expression of the effect of physical land conditions, including climate, on the total suitability for use without damage for crops that require regular tillage, for grazing, for woodland, and for wildlife. Land capability involves consideration of (1) the risks of land damage from erosion and other causes and (2) the difficulties in land use owing to physical land characteristics, including climate (224).

LINEAR PROGRAMMING. An optimization model to determine the maximum or minimum value of a mathematical function, incorporating the objectives of the planners, which is a linear function of a set of variables controlled by the planner, subject to a set of constraints which are also linear functions of the controllable variables (adapted from 492).

MIDGRASS PRAIRIE. See mixed prairie.

MIXEDGRASS PRAIRIE. See mixed prairie.

MIXED PRAIRIE. An extensive grassland in North America lying west of the Tall Grass Prairie (True Prairie, Prairie) and east of the Shortgrass Prairie, which together with the Shortgrass Prairie comprise the Plains in this report. The grassland is codominated by a mixture of tall, short, and mid grasses with a variety of sub-dominant herbaceous and woody species.

MULCH. A natural layer of plant residue on the soil surface, both the largely undecayed coarse layer (fresh mulch) and the decayed and fragmented residuum of fresh mulch (humic mulch) (495).

NATURAL AREA. A physical and biological unit in as near a natural condition as possible which exemplifies typical or unique vegetation and associated biotic, soil, geologic and aquatic features. The unit is maintained in a natural condition by allowing physical and biological processes to operate, usually without direct human intervention (Buckman and Quintus, 1972) (490).

NET PRIMARY PRODUCTION. The net increase in plant biomass within a specified area and time interval, i.e., primary production less that used in metabolic processes (224).

NET RANCH INCOME. Ranch income due to the four factors of production, i.e. land capital, non-land capital, labor and management.

NITROGEN FIXATION. The assimilation of free nitrogen of the atmosphere by microorganisms in the soil or by bacteria in the nodules of certain plants, especially legumes, into organic nitrogenous compounds (489).

NON-LINEAR PROGRAMMING. An optimization model similar to linear programming, except that either the objective function or the constraints, or both, are non-linear functions of the controllable variables.

OBJECTIVE FUNCTION. A mathematical function incorporating the objectives of the planners in an optimization model. The objective function may be linear or non-linear.

OPERATIONS RESEARCH. The use of analytic methods adopted from mathematics for solving operational problems. Among the common scientific techniques used in operations research are mathematical programming, statistical theory, information theory, game theory, Monte Carlo methods, and queueing theory (490).

OPTIMIZATION MODEL. A mathematical model which identifies the most desirable course of action.

OVERGRAZING. Continued overuse creating a deteriorated range (224).

OVERUSE. Utilizing an excessive amount of the current year's growth which, if continued, will result in overgrazing and range deterioration. Syn., over-utilization (224).

PALATABILITY. The relish with which a particular species or plant part is consumed by an animal (224).

PEAK ABOVE-GROUND HERBAGE STANDING CROP. The greatest amount of the standing crop of herbage accumulated during year, as distinguished from other classes of vegetation. See Peak Standing Crop.

PEAK STANDING CROP. The greatest amount of standing crop accumulated during the year, includes recent dead as well as live material produced during the current year (see Standing Crop).

PERCOLATION. The downward movement of water through the soil (491).

PERIODICITY. The seasonal patterns of growth of different species of vegetation, resulting in reduced competition and greater use of the resources of the habitat for plant growth.

PHOTOSYNTHESIS. The synthesis of carbohydrates from carbon dioxide and water by chlorophyll using light as energy with oxygen as a by-product (489).

PITTING. Making shallow pits or basins of suitable capacity and distribution on range to reduce overland flow from rainfall and snowmelt (224).

POTENTIAL EVAPOTRANSPIRATION. The combined loss of water by evaporation and transpiration from a vegetated surface with an adequate supply of water. Used as a descriptor of climate.

PRESENT VALUE OF FUTURE NET RETURNS. Future net return from an investment (i.e. range improvement practice) discounted annually at the current interest or capitalization rate.

PRODUCTION FUNCTION, AGRICULTURAL. A mathematical relationship (frequently presented as a graph) which shows how inputs of various physical factors are related to changes of output--e.g., the effect of different amounts of fertilizer or thinning on the rate of timber production (490).

PROPER USE. A degree and time of use of current year's growth which, if continued, will either maintain or improve the range condition consistent with conservation of other natural resources. Syn., proper utilization (224).

RANCH. A business which derives most of its income from the sale of grazing animals and the animals get most of their food from native range.

RANGE (RANGELAND). A kind of land which is dominated by vegetation useful for grazing or browsing on which husbandry is routinely through management of grazing rather than by renovation and/or cultural treatment (488).

RANGE CONDITION. The state of health of the range expressed in terms of its potential, quantitatively expressed as the departure from relicts of climax.

RANGE MANAGEMENT. A distinct discipline founded on ecological principles and dealing with the husbandry of rangelands and range resources (224).

RANGE SCIENCE. The organized body of knowledge upon which the practice of range management is based (224).

RANGE SITE. A kind of rangeland differing significantly from other kinds of rangeland in its ability to produce kind or amount of climax vegetation and in its response to management.

REFERENCE AREA (COMPARISON AREA). An area with a documented history and/or condition that is used as a standard for comparison (488).

RELICT. A remnant or fragment of a flora that remains from a former period when it was more widely distributed (224). As related to climax, fragments of presently existing flora on areas with a historical record of no disturbance and the plant community is assumed to be in near virgin condition (487).

RESIDUE. The portion of current year's forage growth left remaining after an entire grazing season or a portion thereof.

REST (FROM GRAZING). Absence of livestock grazing on an area for an entire year.

RHIZOME. A horizontal underground stem, usually sending out roots and aboveground shoots from the nodes (224).

RILL EROSION. An erosion process in which numerous small channels of only several inches in depth are formed; occurs mainly on recently cultivated soils (491).

SALINIZATION. The formation of a saline soil by the addition of salts to a non-saline soil, as occurs often in irrigating land with water of a high degree of salinity (489).

SEMIARID. A term applied to climates with a moisture index between -40 and -20 in Thornthwaite's 1948 classification (234) where

$$\text{Moisture index} = \frac{(100 \times \text{water surplus}) - (60 \times \text{water deficit})}{\text{potential evapotranspiration}}$$

SHEET EROSION. The removal of a fairly uniform layer of soil from the land surface by runoff water (491).

SHORTGRASS PRAIRIE. The grassland lying immediately east of the Rocky Mountains, dominated by low-growing grasses, and which makes up the drier portion of the Plains in Colorado, New Mexico, Texas, Oklahoma, and Kansas.

SIMULATION MODEL. A dynamic mathematical model that mimics the functioning of a system or process by the process of step-by-step solution of the equations that describe the system ((492).

SOLODIZED-SOLONETZ SOILS. Soils with a friable surface of varying thickness underlain by a B horizon with hard columnar structure that restricts water and root penetration. The B horizon is of variable thickness, with concentrations of sodium varying from none to very high.

STANDING CROP. The total amount of living plant material, in above ground parts, per unit of space at a given time (224).

NATURAL STEADY-STATE. The culmination of ecological succession (primary autogenic progression), characterized by dynamic fluctuation rather than directional change in ecosystem properties (2).

STOCHASTIC MODEL. A model which does not offer a unique solution but rather a distribution of solutions with the probability of each solution corresponding to some specified probability distribution (492).

STOCKING DENSITY. The number of specified kinds and classes of animals grazing a unit of land at any point in time. May be expressed as animals per acre, hectare, or section, or the reciprocal (area of land/animal). Where dual use is practiced (e.g. cattle and sheep) stocking density is often expressed as animal units per unit of land or the reciprocal (488).

STOCKING RATE. The number of specified kinds and classes of animals grazing (or utilizing) a unit of land for a specific period of time. May be expressed as animals/acre, hectare, or section, or the reciprocal (area of land/animal). Where dual use is practiced (e.g. cattle and sheep), stocking rate is often expressed as animal units/unit of land or the reciprocal (488).

STRATIFICATION. Vertical patterning, above- and below-ground, of different species of vegetation, resulting in reduced competition and greater utilization of the resources of the habitat for plant growth.

SUBHUMID. A term applied to climates with a moisture index between -20 and +20, usually separated into dry subhumid (-20 to 0) and moist subhumid (0 to 20) in Thornthwaite's 1948 classification (234) where

$$\text{Moisture index} = \frac{(100 \times \text{water surplus}) - (60 \times \text{water deficit})}{\text{Potential evapotranspiration}}$$

TDN (TOTAL DIGESTIBLE NUTRIENTS). A common measure of energy available in livestock feed and forages, roughly comparable to digestible energy, and expressed in units of weight or percent.

TILLER. Individual shoots of grassesthat arise from axial or basal buds.

TRANSPIRATION. The loss of water in vapor form from a plant, mostly through the stomata and lenticels. cf. Stoma, Lenticel (489).

TREND (IN RANGE CONDITION). The direction of change in range condition (224).

UNIVERSAL SOIL LOSS EQUATION. An equation used for the design of water erosion control systems. $A = RKLSPC$ wherein A = average annual soil loss in tons per acre per year, R = rainfall factor, K = soil erodibility factor, L = length of slope, S = percent of slope, P = conservation practice factor, and C = cropping and management factor (Soil Conserv. Soc. Amer., 1970) (490).

VEGETATION TYPE. An existing plant community with distinguishable characteristics described in terms of the dominant vegetation present (488).

Literature Cited

1. Heady, H. F. 1975. Rangeland Management. McGraw-Hill Book Co., New York. 460 p.

2. Lewis, J. K. 1969. Range management viewed in the ecosystem framework. pp. 97-187. In: The Ecosystem Concept in Natural Resource Management. G. M. Van Dyne (ed.). Academic Press, New York.

3. Stoddart, L. A., A. D. Smith, and T. W. Box. 1975. Range Management, 3rd Ed. McGraw-Hill Book Co., New York. 532 p.

4. Van Poolen, H. Walt and J. R. Lacey. 1979. Herbage response to grazing systems and stocking intensities. J. Range Manage. 32:250-253.

5. Hart, R. H. 1978. Stocking rate theory and its application to grazing on rangelands. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 547-550. Denver, Colorado.

6. Galt, H. D. and J. L. Kramer. 1978. Grazing systems for range improvements and livestock production in the northern Great Plains. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 534-537. Denver, Colorado.

7. Hart, R. H. 1972. Forage yield, stocking rate, and beef gains on pasture. Herbage Abstracts. 42:345-353.

8. Burslaff, D. F. and L. Harris. 1969. Yearling steer gains and vegetation changes of western Nebraska rangeland under three rates of stocking (a ten year study). Nebraska Agr. Exp. Sta. Bull. SB505.

9. Houston, W. R. and R. R. Woodward. 1966. Effects of stocking rates on range vegetation and beef cattle production in the Northern Great Plains. U.S.D.A. Tech. Bull. 1357. 58 p.

10. Klipple, G. E. and D. F. Costello. 1960. Vegetation and cattle responses to different intensities of grazing on short-grass ranges on the Central Great Plains. U.S.D.A. Tech. Bull. 1216.

11. Sims, P. L., B. E. Dahl, and A. H. Denham. 1976. Vegetation and livestock responses at three grazing intensities on sandhill rangeland in eastern Colorado. Colo. State Univ. Exp. Sta. Tech. Bull. 130.

12. Rauzi, F., E. J. Dyksterhuis, and C. L. Fly. 1968. Water intake on midcontinental rangelands as influenced by soil and plant cover. U.S.D.A. Tech. Bull. 1390. 58 p.

13. Mueggler, W. F. 1965. Cattle distribution on steep slopes. J. Range Manage. 18:255-258.

14. Cook, C. W. 1966. Factors affecting utilization of mountain slopes by cattle. J. Range Manage. 19:200-204.

15. Branson, F. A., G. F. Gifford, and J. R. Owen. 1972. Rangeland Hydrology. Soc. for Range Manage. Range Sci. Ser. 1. Soc. for Range Manage. Denver, Colorado. 84 p.

16. Reardon, P. O., and L. B. Merrill. 1976. Vegetative response under various grazing management systems in the Edwards Plateau of Texas. J. Range Manage. 29:195-198.

17. Bartlett, E. T., G. R. Evans, and R. E. Bemment. 1974. A serial optimization model for ranch mangement. J. Range Manage. 27:233-239.

18. Jameson, D. A., S. A. D'Aquino, and E. T. Bartlett. 1974. Economics and Management Planning of Range Ecosystems. A. A. Balkema, Rotterdam. 244 p.

19. Phelps, C. E. and N. H. Wellborn. 1978. COPLAN: a new tool for range management. Proc. First Inter. Rangeland Congr., Aug. 14-18, 1978, pp. 169-172. Denver, Colorado.

20. Van Dyne, G. M. 1978. Optimal combinations of four large herbivores for shortgrass prairie. Proc. XIII Inter. Grassland Congr. Leipzig, German Democratic Republic.

21. Kautz, J. E. and G. M. Van Dyne. 1978. Comparative analysis of diets of bison, cattle, sheep and pronghorn antelope on shortgrass prairie in northeastern Colorado, U.S.A. Proc. First Inter. Rangeland Congr., Aug. 14-18, 1978, pp. 438-443. Denver, Colorado.

22. Mackie, R. J. 1970. Range ecology and relations of mule deer, elk and cattle in the Missouri River Breaks, Montana. Wildl. Monog. 20:1-79.

23. Bryant, F. C., M. M. Kothmann, and L. B. Merrill. 1979. Diets of sheep, Angora goats, Spanish goats and white-tailed deer under excellent range conditions. J. Range Manage. 32:412-417.

24. Huos, D. L., and J. V. Allen. 1969. Livestock production and profitability comparisons of various grazing systems, Texas Range Station. Tex. Agr. Exp. Sta. B-1089. 14 p.

25. Lange, R. T. 1969. The piosphere: sheep track and dung patterns. J. Range Manage. 22:396-400.

26. Mueggler, W. F. 1965. Cattle distribution on steep slopes. J. Range Manage. 18:255-257.

27. Skovlin. 1965. Improving cattle distribution on western mountain rangelands. U.S.DA.A. Farmers' Bull. 2212.

28. Workman, J. P. and J. F. Hooper. 1968. Preliminary economic evaluation of cattle distribution practices on mountain rangeland. J. Range Manage. 21:301-304.

29. Lewis, J. K. 1980. Range herbivory in the Grassland Biome -- Implications for management. (Manuscript in preparation for Society for Range Manage. Monograph).

30. Bement, R. E. 1969. A stocking-rate guide for beef production on blue grama range. J. Range Manage. 22:83-86.

31. Launchbaugh, J. L., and C. E. Owensby. 1978. Kansas rangelands: Their management based on a half century of research. Kan. Agr. Exp. Sta. Bull. 622. 56 p.

32. Lommasson, T. 1947. Developments in range management: The influence of rainfall on the prosperity of eastern Montana, 1878-1946. U.S. Forest Service Bull. 7.

33. Dyksterhuis, E. J. 1958. Range conservation as based on sites and condition classes. J. Soil and Water Conserv. 13:151-155.

34. Rice, R. W., J. F. Nagy, and D. G. Peden. 1971. Functional interaction of large herbivores on grasslands. pp. 241-265. In: N. R. French (Ed.) Preliminary Analysis of Structure and Function in Grasslands. Range Sci. Ser. No. 10. Colo. State Univ., Fort Collins. 387 p.

35. Kothmann, M. M., G. W. Mathis, and W. J. Waldrip. 1971. Cow-calf response to stocking rates and grazing systems on native range. J. Range Manage. 24:100-105.

36. Hyder, D. N. 1974. Morphogenesis and mangement of perennial grasses in the United States. pp. 89-98. In: K. W. Kreitlow and R. H. Hart (Ed.) Plant morphogenesis as the basis for scientific management of range resources. Proc. Workshop, U.S.-Australia Rangelands Panel, Berkely, Calif., March 29-April 5, 1971. U.S.D.A. Misc. Publ. 1271. 232 p.

37. Dahl, B. E. and D. N. Hyder. 1977. Developmental morphology and management implications. pp. 257-290. In: R. E. Sosebee (Ed.) Rangeland Plant Physiology. Range Science Series No. 4. Soc. Range Manage., Denver, Colorado. 290 p.

38. Trlica, M. J. 1977. Distribution and utilization of carbohydrate reserves in range plants. pp. 73-96. In: R. E. Sosebee (Ed.) Range Plant Physiology. Range Science SeriesNo. 4. Soc. Range Manage. Denver, Colorado. 290 p.

39. Booysen, P. de V., and N. M. Tainton. 1978. Grassland management: Principles and practices in South Africa. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 551-554. Denver, Colorado.

40. Savory, A. 1968. A holistic approach to ranch management using short duration grazing. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978. pp. 555-557. Denver, Colorado.

41. Kothman, M. M., W. J. Waldrip, and G. W. Mathis. 1978. Rangeland vegetation of the Rolling Plains of Texas -- Response to grazing management and climatic patterns. Proc. First Intern. Rangeland Congr., Augu. 14-18, 1978. pp. 606-609. Denver, Colorado.

42. Scott, J. A., N. R. French, and J. W. Leetham. 1979. Patterns of consumption in grasslands. pp. 89-105. *In*: N. R. French (Ed.) Perspectives in Grassland Ecology. Results and Applications of the US/IBP Grassland Biome Study. Springer-Verlag, New York. 204 p.

43. Smolik, J. D. 1978. Effect of nematicide, fungicide and insecticide treatment on growth of range grasses. S.D. Acad. Sci. 57:179-180.

44. Smolik, J. D. 1974. Nematode studies at the Cottonwood site. US/IBP Grassland Biome Tech. Rep. 251. Colo. State Univ. Fort Collins, Colorado. 80 p.

45. Hewitt, G. B., E. W. Huddleston, R. J. Lavigne, D. N. Uechert, and J. G. Watts. 1974. Rangeland Entomology. Range Science Ser. No. 2. Soc. Range Manage. Denver, Colorado. 127 p.

46. McDaniel, B. 1971. The role of invertebrates in the grassland biome, pp. 267-315. *In*: N. R. French (Ed.) Preliminary Analysis of Structure and Function in Grasslands. Range Sci. Ser. No. 10. Colo. State Univ., Fort Collins. 387 p.

47. Anderson, N. L. 1973. The vegetation of rangeland sites associated with some grasshopper studies in Montana. Mont. Agr. Exp. Sta. Bull. 668. 47 p.

48. Haws, B. A. 1978. Economic impacts of *Labops hesperius* on the production of high quality range grasses. Final report of Utah Agr. Exp. Sta. to Four Corners Reg. Com. Utah State Univ., Logan. 269 p.

49. Haws, B. A. 1979. Something is eating more grass than our livestock. Rangelands 1:135-138.

50. Vallentine, J. F. 1971. Range Development and Improvements. Brigham Young Univ. Press, Provo, Utah. 516 p.

51. Foster, M. A., and J. Stubbendieck. 1980. Effects of the Plains pocket gopher (*Geomys bursarius*) on rangeland. J. Range Manage. 33:74-78.

52. Koford, C. B. 1958. Prairie dogs, white faces, and blue grama. Wildl. Monogr. No. 3. 78 p.

53. Klatt, L. E., and D. Hein. 1978. Vegetative differences among active and abandoned towns of black-tailed prairie dogs (*Cynomys ludovicianus*). 1978. J. Range Manage. 31:315-317.

54. Summers, C. A. and R. L. Linder. 1978. Food habits of the black-tailed prairie dog in western South Dakota. J. Range Manage. 31:134-136.

55. Bonham, C. D., and A. Lerwick. 1976. Vegetation changes induced by prairie dogs on shortgrass range. J. Range Manage. 29:221-225.

56. Flake, L. D. 1973. Food habits of four species of rodents on a shortgrass prairie in Colorado. J. Mammal. 54:636-647.

57. McAdoo, J. K. and J. A. Young. 1980. Jackrabbits. Rangelands 2:135-138.

58. Johnson, L. E., L. R. Albee, R. O. Smith, and A. L. Moxon. 1951. Cows, calves, and grass. South Dakota Agr. Exp. Sta. Bull. 412. 39 p.

59. Hickey, W. C. N. D. A discussion of grazing management systems and some pertinent literature. U.S.D.A. Forest Service. Multilith. Denver, Colorado.

60. Smolik, J. D. 1977. Effect of nematicide treatment on growth of range grasses in field and glasshouse studies. pp. 257-260. In: J. K. Marshall (Ed.) Proc. of Belowground Ecosystem Symposium. Range Science Ser. No. 26. Colo. State Univ., Fort Collins.

61. Launchbaugh, L. L., C. E. Owensby, F. L. Schwartz, and L. R. Corah. 1978. Grazing management to meet nutritional and functional needs of livestock. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 541-546.

62. Cook. C. W. 1966. Carbohydrate reserves in plants. Utah Agr. Exp. Sta. Res. Ser. 31:1-47.

63. Holmes, N. D., D. S. Smith, and A. Johnston. 1979. Effect of grazing by cattle on the abundance of grasshoppers on fescue grassland. J. Range Manage. 32:310-311.

64. Hewitt, G. B. 1977. Review of forage losses caused by rangeland grasshoppers. U.S.D.A. Agr. Res. Serv. Misc. Publ. 1348.

65. Merrill, L. B., and J. E. Miller. 1961. Economic analysis of year-long grazing rate studies on Substation No. 14, near Sonora. Tex. Agr. Exp. Sta. Misc. Pub. 484. 8 p.

66. Vavra, M., R. W. Rice, and R. E. Bement. 1973. Chemical composition of the diet, intake, and gain of yearling cattle on different grazing intensities. J. Anim. Sci. 36:411-414.

67. Launchbaugh, J. L. 1957. The effect of stocking rate on cattle gains and on native shortgrass vegetation in west-central Kansas. Kansas Agr. Exp. Sta. Bull. No. 394.

68. Smoliak, J., J. F. Dormaar, and A. Johnston, 1972. Long-term grazing effects on Stipa-Bouteloua prairie soils. J. Range Manage. 25:246-250.

69. Sarvis, J. T. 1941. Grazing investigations in the northern Great Plains. North Dakota Agr. Exp. Sta. Bull. 308. 110 p.

70. Lewis, J. K., G. M. Van Dyne, L. R. Albee, and F. W. Whetzal. 1956. Intensity of grazing: Its effect on livestock and forage production. South Dakota Agr. Exp. Sta. Bull. 459. 44 p.

71. McGinnies, W. J. 1971. Effects of controlled plant spacing on growth and mortality of three range grasses. Agron. J. 63:868-870.

72. Van Dyne, G. M., N. R. Brockington, Z. Szocs, J. Duek, and C. A. Ribic. 1980. Large herbivore subsystems. pp. 269-537. In: A. J. Breymeier and G. M. Van Dyne (Eds.) Grasslands, Systems Analysis and Man. Cambridge Univ. Press, England.

73. Gee, C. Kerry, R. S. Magleby, D. B. Nielson, and D. M. Stevens. 1977. Factors in the decline of the western sheep industry. U.S.D.A. Econ. Res. Ser. Agr. Econ. Rep. No. 377. 31 p.

74. Gee. C. Kerry. 1979. Cattle and calf losses to predators -- feeder cattle enterprises in the United States. J. Range Manage. 32:152-154.

75. Gee, C. K., R. S. Magleby, W. R. Bailey, R. L. Gum, and L. M. Arthur. 1977. Sheep and lamb losses to predators and other causes in the western United States. U.S.D.A. Agr. Econ. Res. Serv., Agr. Econ. Rep. No. 369. 41 p.

76. McAdoo, J. K., and D. A. Klebenow. 1978. Predation on sheep range with no predator control. J. Range Manage. 31:111-114.

77. DeLorenzo, D. G., and V. W. Howard, Jr. 1976. Evaluation of sheep losses on a range lambing operation without predator control in southeastern New Mexico. Final Rep. to the U.S. Fish and Wildl. Serv., Denver Res. Center. New Mexico State Univ., Las Cruces. 34 p.

78. Munoz, J. R. 1976. Causes of sheep mortality at the Cook Ranch, Florence, Montana, 1975-76. Annual Rep. to U.S. Fish and Wildl. Serv., Denver Res. Center. Contract No. 14-16-0008-1135. 44 p.

79. Wagner, F. H. 1975. The predator-control scene as of 1974. J. Range Manage. 28:4-10.

80. Dorrance, M. J. and J. Bourne. 1980. An evaluation of anti-coyote electric fencing. J. Range Manage. 33:385-387.

81. Hornocker, M. G. 1972. Predator ecology and management -- what now? J. Wildl. Manage. 36:401-404.

82. Howard, W. E. 1974. The Biology of Predator Control. Addison-Wesley Pub. Co., Reading, Ma. 48 p.

83. Johnson, J., and F. R. Gartner. 1975. Perspectives on predator management. J. Range Manage. 28:18-21.

84. Meinzer, W. P., D. N. Uekert, J. T. Flinders. 1975. Food niche of coyote in the Rolling Plains of Texas. J. Range Manage. 28:22-27.

85. Bolen, E. G. 1975. Eagles and sheep: A viewpoint. J. Range Manage. 28:11-17.

86. Cain, S. A., J. A. Kadlec, D. L. Allen, R. A. Cooley, M. H. Hornocker, A. S. Leopold, and F. H. Wagner. 1972. Predator control--1971: Report to the Council on Environmental Quality and the Department of the Interior by the Advisory Committee on Predator Control. Univ. Mich. Press, Ann Arbor. 207 p.

87. U. S. Environmental Protection Agency, Office of Pesticides Programs. 1972. EPA Compendium of Registered Pesticides. Vol. IV. Rodenticides, and Mammal, Bird, and Fish Toxicants. Supt. of Doc. U.S. Govt. Print. Office. Washington, D. C.

88. U.S.D.I., Office of Endangered Species. 1973. Threatened Wildlife of the United States. U.S.D.I. Bur. of Sport Fisheries and Wildl. Resource Pub. 114. 289 p.

89. Crawford, J. E. 1972. Habitat management for rare and endangered wildlife species on the public domain. Proc. West. Assoc. State Game and Fish Comm. 52: 409-419.

90. Lokeman, J. T. 1973. Waterfowl production on stock-watering ponds in the Northern Plains. J. Range Manage. 26:179-184.

91. Sanderson, G. C. 1977. Management of Migratory Shore and Upland Game Birds in North America. Internat. Assoc. Fish and Wildl. Agencies, Washington, D. C. 358 p.

92. Evans, K. E., and G. E. Probasco. 1977. Wildlife of the prairies and plains. U.S.D.A. For. Ser. Gen. Tech. Rep. NC-29. 18 p.

93. Linder, R. L., and C. N. Hillman. 1973. Proc. of the black-footed ferret and prairie dog workshop. Spet. 4-8, 1973. South Dakota State Univ., Brookings. 208 p.

94. Townsend, J. E., and R. J. Smith. 1977. Improving fish and wildlife benefits in range management. Proc. of Seminar. U.S.D.I. Fish and Wildl. Serv., Washington, D. C. 118 p.

95. Kaiser, P. H., S. S. Berlinger, and R. H. Fredrickson. 1979. Response of blue-winged teal to range management on waterfowl production areas in southeastern South Dakota. J. Range Manage. 32:295-298.

96. Gjersing, F. M. 1975. Waterfowl production in relation to rest-rotation grazing. J. Range Manage. 28:37-42.

97. Soutierre, E. C., and E. G. Bolen. 1976. Mourning dove nesting on tobosa grass-nesquite rangelands sprayed with herbicides and burned. J. Range Manage. 29:226-231.

98. Jackson, A. S. 1965. A handbook for bobwhite quail management in the West Texas Rolling Plains. Tex. Parks and Wildl. Dept. Bull. 48. 77p.

99. Crawford, J. A., and E. G. Bolen. 1976. Effects of land use on lesser prairie chickens in Texas. J. Wildl. Manage. 40:96-104.

100. Chamrad, A. D., and J. D. Dodd. 1972. Prescribed burning and grazing for prairie chicken habitat manipulations in the Texas Coastal Prairie. Tall Timbers Fire Ecol. Conf. 12:257-276.

101. Kirsch, L. M., and A. D. Kruse. 1972. Prairie fires and wildlife. Tall Timbers Fire Ecol. Conf. 12:289-305.

102. Vassar, J. W., and R. F. Henderson. 1977. Kansas upland game and its management. Kan. Agr. Ext. Cir. 564. 24 p.

103. Smith, D. R. 1975. Proceedings of the symposium on management of forests and range habitats of nongame birds. U.S.D.A. Forest Serv. Gen. Tech. Rep. WO-1. 343 p.

104. Cooper, C. F., and W. C. Jolly. 1969. Ecological effects of weather modification: a problem analysis. Univ. Michigan, School Natur. Resources, Ann Arbor.

105. Cook, C. W. 1975. Possible benefits of weather modification on rangeland production. pp. 13-14. In: L. O. Grant and J. D. Reid (Ed.) Workshop for an Assessment of the Present and Potential Role of Weather Modification in Agricultural Production. Colo. State Univ., Dep. Atmospheric Sci., Fort Collins. Atmospheric Sci. Pap. No. 236.

106. Ballard, W., and D. E. Ryerson. 1973. Impacts of induced rainfall on the Great Plains of Montana -- Section 1: Range livestock production. Mont. Agr. Exp. Sta. Res. Rep. 42.

107. Newbauer, J. J. III, L. M. White, R. M. Mog, and D. A. Perry. 1980. Effects of increased rainfall on native forage production in eastern Montana. J. Range Manage. 33:246-250.

108. Perry, D. A. 1976. The effects of weather modification on Northern Great Plains grasslands: a preliminary assessment. J. Range Manage. 29:272-278.

109. Coupland, R. T. 1958. The effects of fluctuations in weather upon grasslands of the Great Plains. Bot. Rev. 24:273-317.

110. Cleveland, H. (Chairman). 1978. The Management of Weather Resources, Vol. I -- Proposals for a National Policy and Program. U.S. Dep. Comm., Washington, D. C. 229 p.

111. National Academy of Sciences -- National Research Council. 1966. Weather and Climate Modification: Problems and Prospects. N.A.S. - N.R.C. Pub. No. 1350. Vols. I and II. Washington, D. C.

112. Baily, A. W. 1978. Use of fire to manage grasslands of the Great Plains: Northern Great Plains and adjacent forests. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978. pp. 691-693. Denver, Colorado.

113. Gartner, F. R., R. I. Butterfield, W. W. Thompson, and L. R. Roath. 1978. Prescribed burning of range ecosystems in South Dakota. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978. pp. 687-690. Denver, Colorado.

114. Wright, H. A. 1978. Use of fire to manage grasslands of the Great Plains: Central and Southern Great Plains. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 694-696. Denver, Colorado.

115. Wright, H. A., and A. W. Bailey. 1980. Fire ecology and prescribed burning in the Great Plains — a research review. U.S.D.A. Gen. Tech. Rep. INT-77. 60 p.

116. Woolfolk, J. S., E. F. Smith, R. R. Schalles, B. E. Brent, L. H. Harbers, and C. E. Owensby. 1975. Effects of nitrogen fertilization and late-spring burning of bluestem range on diet and performance of steers. J. Range Manage. 28:190-193.

117. Horvath, J., D. Schweitzer, and E. Bell. 1978. Grazing on National Forest System lands: cost of increasing capacity in the Northern Region. U.S.D.A. For. Ser. Res. Pap. INT-215. 56 p.

118. Burzlaff, D. F. and L. A. Daigger. 1972. Fertilizing native range. Neb. Quarterly 19:19-20.

119. Goetz, H., P. E. Nyren, and D. E. Williams. 1978. Implications of fertilizers in plant community dynamics of Northern Great Plains. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 671-674. Denver, Colorado.

120. McIlvain, E. H. 1961. Summary of range and pasture fertilization studies in the Southern Great Plains. U.S.D.A. Agr. Res. Serv. Woodward, Oklahoma. Mimeo. 29 p.

121. Morrow, L. A., R. J. Lorenz, and G. A. Rogler. 1978. Using nitrogen fertilizer to renevate overgrazed mixed prairie grasslands in the Northern Great Plains. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 675-677. Denver, Colorado.

122. Rauzi, F., R. L. Lang, and L. I. Painter. 1968. Effects of nitrogen fertilizer on native rangeland. J. Range Manage. 21:287-291.

123. Reynolds, E. B., J. F. Fudge, and J. M. Jones. 1951. Supplying phosphorous to range cattle through the fertilization of range land. Texas Agr. Exp. Sta. Bull. 773.

124. Wight, J. Ross, and A. L. Black. Range fertilization: plant responses and water use. J. Range Manage. 32:345-349.

125. Wight, J. Ross, and A. L. Black. Soil water recharge in a fertilized mixed prairie plant community. J. Range. Manage. 31:280-282.

126. Wight, J. Ross. 1976. Range fertilization in the Northern Great Plains. J. Range Manage. 29:180-185.

127. Wight, J. R., and A. L. Black. 1979. Range fertilization: plant response and water use. J. Range Manage. 32:345-349.

128. Becker, D. A., and J. J. Crockett. 1976. Nitrogen fixation in some prairie legumes. Amer. Midl. Natural. 96:133-143.

129. Charley, J. L. 1977. Mineral cycling in rangeland ecosystems. pp. 215-256. In: R. E. Sosebee (Ed.) Range Plant Physiology. Range Science Series No. 4. Soc. Range Manage., Denver, Colorado. 290 p.

130. Pettit, R. D., and R. E. Fagan. 1974. Yield and protein content of sandyland range forages as affected by three nitrogen fertilizers. J. Range Manage. 27:211-213.

131. Soiseth, R. J., J. R. Wright, and J. K. Aase. 1974. Improvement of panspot (solonetzic) range sites by contour furrowing. J. Range Manage. 27:107-110.

132. Gartner, F. R. and R. I. Butterfield. 1978. Improving forage production on claypan soils. South Dakota Agr. Exp. Sta. A.S. Ser. 78-28. pp. 71-75.

133. Gartner, F. R., W. W. Thompson, R. E. Moul, and W. R. Trevillyan. 1969. Ripping of panspots range site. S.D. Agr. Exp. Sta. A.S. Ser. 69-31. pp. 13-15.

134. Wight, J. Ross. 1976. Land surface modifications and their effects on range and forest watersheds. pp. 165-174. In: H. F. Heady, D. H. Falkenborg and J. P. Riley (Eds.) Watershed Management on Range and Forest Lands. Utah State Univ., Logan.

135. Nichols, J. T. 1966. Effect of ripping on western wheatgrass range. Livestock field day, Newell Field Sta. South Dakota Agr. Exp. Sta. May 10, 1966. pp. 31-32.

136. Nichols, J. T. 1969. Range improvement practices on deteriorated dense clay wheatgrass range in western South Dakota. South Dakota Agr. Exp. Sta. Bull. 552. 23 p.

137. Branson, F. A., R. F. Miller, and I. S. McQueen. 1966. Contour furrowing, pitting and ripping on rangelands of the western United States. J. Range Manage. 19:182-190.

138. Wight, J. R., E. L. Neff, and R. J. Soiseth. 1978. Vegetation response to contour furrowing. J. Range Manage. 31:97-101.

139. Wight, J. Ross, F. H. Siddoway, R. J. Kartchner, and J. L. Bishop. 1978. Contour furrows seeded with grasses and legumes increase production on semiarid range sites. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 643-644. Denver, Colorado.

140. Dudley, R. F., and E. B. Hudspeth. 1964. Pitting and listing treatments on native shortgrass rangeland. Tex. Agr. Exp. Sta. Prog. Rep. 2313. 7 p.

141. Houston, W. R. 1971. Range improvement methods and environmental influences in the Northern Great Plains. U.S.D.A. Prod. Res. Rep. 130. 13 p.

142. Rauzi. F. 1968. Pitting and interseeding native shortgrass rangeland. Wyoming Agr. Exp. Sta. Res. J. 17. 14 p.

143. Rauzi, F. 1974. Mechanical and chemical range renovation in southeastern Wyoming. J. Range Manage. 27:48-52.

144. Rauzi, F., and R. L. Lang. 1957. Range pitting. Crops and Soils 9:24.

145. White, L. M., and J. Ross Wight. 1974. Interseeding and pitting on a sandy range site in eastern Montana. J. Range Manage. 27:206-210.

146. Branson, F. A. 1956. Range forage production changes on a water spreader in southeastern Montana. J. Range Manage. 9:187-191.

147. McGinnies, W. J. 1978. Thinning of blue grama range for increased seed and forage production. Proc. First Intern. Rangeland Congr., August 14-18, 1978, pp. 645-646. Denver, Colorado.

148. Houton, W. R. 1960. Effects of water spreading on range vegetation in eastern Montana. J. Range Manage. 13:289-293.

149. French, N. H. 1978. Water spreading around the world. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 314-317. Denver, Colorado.

150. Riveland, N., E. W. French, and A. A. Schneiter. 1975. Perennial forage production with a water spreading system. N. D. Farm Res. 32:15-20.

151. Cox, M. B., H. A. Daniel, and H. M. Elwell. 1971. Terraces on grassland. Okla. Exp. Sta. Bull. 373.

152. Miller, R. F., I. S. McQueen, F. A. Branson, L. M. Shown, and W. Buller. 1969. An evaluation of range flood-water spreaders. J. Range Manage. 22:246-257.

153. Hubbard, W. A., and S. Smoliak. 1953. Effect of contour dikes on shortgrass prairie. J. Range Manage. 6:55-62.

154. Magee, A. C. 1957. Goats pay for clearing Grand Prairie rangelands. Texas Agr. Exp. Sta. Misc. Pub. 206.

155. Smith, E. F. and C. E. Owensby. 1978. Intensive-early stocking and season-long stocking of Kansas Flint Hills range. J. Range Manage. 31:14-17.

156. Johnston, A., and R. W. Peake. 1960. Effect of selective grazing by sheep on the control of leafy spurge (*Euphorbia esula* L.). J. Range Manage. 13:192-195.

157. Adams, T. E. Jr., and C. L. Hughes. 1977. Want biological brush control? Try goats! Rangeman's J. 4:4.

158. Cook, C. W. 1942. Insects and weather as they influence growth of cactus on the Central Great Plains. Ecol. 23:209-214.

159. Goeden, R. D., L. A. Andres, T. E. Freeman, P. Harris. 1974. Present status of projects on the biological control of weeds with insects and plant pathogens in the United States and Canada. Weed. Sci. 22:490-495.

160. Huffaker, C. B. 1971. Biological Control. Plenum Press, New York. 470 p.

161. Huffaker, C. B., and P. S. Messenger. 1976. Theory and Practice of Biological Control. Academic Press, New York. 788 p.

162. Ueckert, D. N., K. L. Polk, and C. R. Ward. 1971. Mesquite twig girdler: A possible means of mesquite control. J. Range Manage. 24:116-118.

163. Scifres, C. J. 1980. Brush Management, Principles and Practices for Texas and the Southwest. Texas A & M Univ. Press, College Station. 360 p.

164. Scifres, C. J. (Ed.). 1973. Mesquite. Growth and development, management, economics, control, uses. Texas Agr. Exp. Sta. Res. Mon. 1. 84 p.

165. Schuster, J. L. 1978. Poisonous plant management problems and control measures on U.S. rangelands, pp. 23-34. In: Effects of Poisonous Plants on Livestock. Academic Press, Inc., New York.

166. Quinton, D. A., R. G. Horejsi, and J. T. Flinders. 1979. Influence of brush control on white-tailed deer diets in north-central Texas. J. Range Manage. 32:93-97.

167. Beck, D. L., R. E. Sosebee, and E. B. Herndon. 1975. Control of honey mesquite by shredding and spraying. J. Range Manage. 28:487-490.

168. Mathis, G. W., M. M. Kothman, and W. J. Waldrip. 1971. Influence of rootplowing and seeding on composition and forage production of native grasses. J. Range Manage. 24:43-47.

169. Scifres, C. J. 1977. Herbicides and the range ecosystem: residues, research and the role of rangemen. J. Range Manage. 30:86-91.

170. Stritzke, J. F. 1975. Germination characteristics and chemical control of horehound. J. Range Manage. 28:225-226.

171. Gesink, R. W., H. P. Alley, and G. A. Lee. 1973. Vegetative response to chemical control of broom snakeweed on a blue grama range. J. Range Manage. 26:139-143.

172. Houston, W. R. 1977. Species susceptibility to atrazine herbicide on shortgrass range. J. Range Manage. 30:50-52.

173. Morrow, L. A., and M. K. McCarty. 1976. Effect of repeated herbicide applications on green sagewort in north central Nebraska. J. Range Manage. 29:413-414.

174. McCarty, M. K., and C. J. Scifres. 1972. Herbicide control of weatern ragweed in Nebraska pastures. J. Range Manage. 25:290-292.

175. Dahl, B. E., R. E. Sosebee, J. P. Goen, and C. S. Brumley. 1978. Will mesquite control with 2,4,5-T enhance grass production? J. Range Manage. 31:129-131.

176. Bovey, R. W., R. E. Meyer, and H. L. Morton. 1972. Herbage production following brush control with herbicides in Texas. J. Range Manage. 25:136-142.

177. Scifres, C. J., G. P. Durham, and J. L. Mutz. 1977. Range forage production and consumption following aerial spraying of mixed brush. Weed Sci. 25:48-54.

178. Scifres, C. J. and J. L. Mutz. 1978. Herbaceous vegetation changes following applications of tebuthuiron for brush control. J. Range Manage. 31:375-378.

179. Scifres, C. J., and M. M. Kothmann. 1976. Site relations, regrowth characteristics, and control of lotebush with herbicides. J. Range Manage. 29:154-157.

180. Whitson, R. E., S. L. Beasom, and C. J. Scifres. 1977. Economic evaluation of cattle and white-tailed deer responses to aerial spraying of mixed brush. J. Range Manage. 30:214-217.

181. Schumacher, C. M. 1964. Range interseeding in Nebraska. J. Range Manage. 17:132-137.

182. Houston, W. R., and R. E. Adams. 1971. Interseeding for range improvement in the Northern Great Plains. J. Range Manage. 24:457-461.

183. Rauzi, F., and R. L. Lang. 1976. Grazing: Solid-seeded, wide-seeded, narrow-interseeded and native pastures in southeastern Wyoming. Wyoming Agr. Exp. Sta. Res. J. 109. 15 p.

184. Nyren, P. E., H. Goetz, and D. Williams. 1978. Interseeding of native mixed prairie in the Great Plains. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, pp. 636-638. Denver, Colorado.

185. Hervey, D. F. 1960. Improving Great Plains rangelands by interseeding. Proc. VIII. Intern. Grassland Congr., p. 216-220.

186. Wight, J. R., and L. M. White. 1974. Interseeding and pitting on a sandy range site in eastern Montana. J. Range Manage. 27:206-210.

187. Robertson, T. E., Jr., and T. W. Box. 1969. Interseeding sideoats grama on the Texas High Plains. J. Range Manage. 22:243-245.

188. Willard, E. E., and J. L. Schuster. 1971. An evaluation of an interseeded sideoats grama stand four years after establishment. J. Range Manage. 24:223-226.

189. Cordova, F. J., J. D. Wallace, and R. D. Pieper. 1978. Forage intake by grazing livestock: A review. J. Range Manage. 31:430-438.

190. Horn, F. P., J. P. Telford, J. E. McCrosky, D. F. Stephens, J. V. Whiteman, and R. Totusek. 1979. Relationship of animal performance and dry matter intake to chemical constituents of grazed forage. J. Anim. Sci. 49:1051-1058.

191. Rice, R. W., J. G. Morris, B. T. Maeda, and R. L. Baldwin. 1974. Simulation of animal functions in models of production systems: ruminants on the range. Fed. Proc. 33:188-195.

192. McNarnee, M. A., and Kinne, E. A. 1967. Pasture and range fences. Mountain States Regional Pub. No. 2R. Univ. of Wyoming, Laramie. 32 p.

193. Mapston, R. D., R. S. Zobell, K. B. Winter, and W. D. Dooley. 1970. A pass for antelope in sheep-tight fences. J. Range Manage. 23:457-459.

194. Moore, R. A., H. G. Young, M. E. Larson, and G. B. Haiwick. 1968. Long span fences. South Dakota Agr. Exp. Sta. Bull. 546.

195. Larson, J. E. 1980. Revegetation Equipment Catalog. Prepared for the Vegetative Rehabilitation and Equipment Workshop. U.S.D.A. Forest Serv. Missoula, Montana. 198 p.

196. Ueckert, D. N., and J. E. Huston (Eds.). 1980. Rangeland resources research. Texas Agr. Exp. Sta. Consolidated Prog. Rep. 3665. 112 p.

197. Tannehill, I. R. 1947. Drought: Its causes and effects. Princeton Univ. Press, Princeton, N. J.

198. Dort, W., Jr. 1959. Geomorphology of the southern Great Plains in relation to livestock production. J. Range Manage. 12:292-295.

199. Klemmedson, J. D. and R. B. Murray. 1963. Use and measurement of site factors and soil properties in evaluation of range site potential. Misc. Publ. U.S. Dept. Agric. No. 940, pp. 68-77.

200. Klingebiel, A. A. and P. H. Montgomery. 1961. Land-capability classification. Agric. Handbook For. Serv. U.S. No. 210.

201. Osborn, B. 1956. Cover requirements for the protection of range sites and biota. J. Range Manage. 9:75-80.

202. Whitman, W. C. 1974. Influence of grazing on the microclimate of Mixed Grass Prairie. pp. 207-218. U.S.D.A. Misc. Pub. 1271.

203. Sampson, A. W., and L. H. Wehl. 1918. Range preservation and its relation to erosion control on western grazing lands. U.S.D.A. Bull. No. 675. 35 p.

204. Gifford, G. F. 1980. Vegetation allocation for meeting site requirements --one viewpoint. National Research Council, Commission on Natural Resources, Committee on Developing Strategies for Rangelands Management, Forage Allocation Workshop, November 17-19, 1980, Albuquerque, N.M.

205. Chepil, W. S. and N. P. Woodruff. 1963. The physics of wind erosion and its control. Adv. Agron. 15:211-302.

206. Copeland, D. L., Jr. 1965. Land use and ecological factors in relation to sediment yields, pp. 72-84. U.S.D.A. Misc. Publ. No. 970.

207. Dadkah, M., and G. F. Gifford. 1980. Influence of vegetation, rock cover, and trampling on infiltration rates and sediment production. Water Res. Bull. 16: in press.

208. Lyles, L., and B. E. Allison. 1976. Wind erosion: the protecting role of simulated standing stubble. Trans. A.S.A.E. 19:61-64.

209. McGinty, W. A., F. E. Smeims, and L. B. Merrill. 1979. Influence of soil, vegetation and grazing management on infiltration rate and sediment production of Edwards Plateau rangeland. J. Range Manage. 32:33-37.

210. Packer, R. E. 1953. Effects of trampling disturbance on watershed condition, runoff and erosion. J. For. 51:28-31.

211. Hanson, C. L., G. R. Kuhlman, and J. K. Lewis. 1978. Effect of grazing intensity and range condition on hydrology of western South Dakota ranges. South Dakota Agr. Exp. Sta. Bull. 647. 54 p.

212. Wolff, D. N. 1970. Grassland infiltration phenomena. U.S. Intern. Biol. Progr., Grassland Biome Tech. Rep. 54. 104 p.

213. Zingg, A. W. 1954. The wind erosion problem in the Great Plains. Trans. Amer. Geophys. Union 32:252:258.

214. Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley and Sons, New York. 315 p.

215. U. S. Department of Interior, Fish and Wildlife Service. 1979. List of endangered and threatened wildlife and plants (replublication). Federal Register, Jan. 17, 1979, Part II:3635-3654.

216. Sims, P. L., J. S. Singh, and W. K. Lauenroth. 1978. The structure and function of ten western North American grasslands. I. Abiotic and vegetational characteristics. J. Ecol. 66:251-285.

217. Sims, P. L., and J. S. Singh. 1978. The structure and function of ten western North American grasslands. II. Intraseasonal dynamics in primary producer compartments. J. Ecol. 66:547-572.

218. Sims, P. L., and J. S. Singh. 1978. The structure and function of ten western North American gresslands. III. Net primary production, turnover and efficiences of energy capture and water uses. J. Ecol. 66:573-597.

219. Sims, P. L., and J. S. Singh. 1978. The structure and function of ten western North American grasslands. IV. Compartment transfers and energy flow within the ecosystem. J. Ecol. 66:983-1009.

220. Woodmansee, R. G., J. L. Dodd, R. A. Bowman, F. E. Clark, and C. E. Dickinson. 1978. Nitrogen budget of a shortgrass prairie ecosystem. Oecologia (Berlin) 34:363-376.

221. Woodmansee, R. G. 1978. Addition and losses of nitrogen in grassland ecosystems. Bio Science 28:448-453.

222. Paul, E. A. 1976. Nitrogen cycling in terrestrial ecosystems. Environmental Biogeochemistry 1:225-243.

223. Clark, F. E., C. V. Cole, and R. A. Bowman. 1980. Nutrient cycling, Chapter 8, pp. 659-712. In: A. J. Breymeyer and G. M. Van Dyne (Eds.) Grasslands, Systems Analysis and Man. International Biological Programme 19. Vol. 2. Cambridge University Press, London.

224. Range Term Glossary Committee. 1974. A glossary of terms used in range management, 2nd ed. Society for Range Management, Denver, Colorado. 36 p.

225. Forest-Range Task Force. 1972. The Nation's Range Resources -- A Forest-Range Environmental Study. U.S.D.A. Forest Service. Forest Res. Rep. 19. 147 p.

226. U.S.D.A. Forest Service. 1980. An Assessment of the Forest and Range Land Situation in the United States. U.S.D.A. Forest Service FS-345. 631 p.

227. Hunt, C. B. 1972. Physiography of the United States. W. H. Freeman Co.

228. U.S.D.A. Soil Conservation Service. 1975. Soil Taxonomy. A Basic System of Classification for Making and Interpreting Soil Surveys. Ag. Handb. No. 436. 754 p.

229. Buckman, H. O., and N. C. Brady. The Nature and Properties of Soils. 7th Ed. Macmillan Co., New York. 653 p.

230. Trieste, D. J. and G. F. Gifford. 1980. Application of the universal soil loss equation to rangelands on a per-storm basis. J. Range Manage. 33:66-70.

231. Bryson, R. A., and F. K. Hare (Eds.). 1974. Climates of North America. Elsevier Scientific Publ. Co., New York. 420 p.

232. Borchert, J. R. 1950. The climate of the central North American grassland. Ann. Assoc. Amer. Geogr. 40:1-39.

233. Transeau, E. N. 1936. The prairie peninsula. Ecology 16:423-437.

234. Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. Geogr. Rev. 38:55-94.

235. Rasmussen, J. L. 1971. Abiotic factors in grassland ecosystem analysis and function, pp. 11-34. In: N. R. French (Ed.) Preliminary Analysis of Structure and Function in Grasslands. Range Science Dep. Ser. 10, Colo. State Univ., Ft. Collins. 387 p.

236. Thornthwaite, C. W., and J. R. Mother. 1957. Instructions for computing potential evapotranspiration and water balance. Drexel Inst. Technol., Lab. Climatol., Pub. Climatol. 30(3):181-311.

237. Lewis. J. K. 1971. The grassland biome: a synethesis of structure and function, 1970, pp. 317-387. In: N. R. French (Ed.) Preliminary Analysis of Structure and Function in Grasslands. Range Sci. Dep. Ser. 10, Colo. State Univ., Ft. Collins. 387 p.

238. Van Dyne, G. M. 1971. The U.S. IBP Grassland Biome Study -- An overview. pp. 1-9. In: N. R. French (Ed.) Preliminary Analysis of Structure and Function in Grasslands. Range Sci. Dep., Sci. Ser. 10, Colo. State Univ., Ft. Collins. 387 p.

239. Markham, C. G. 1970. Seasonality of precipitation in the United States. Ann. Assoc. Amer. Geogr. 60:593-597.

240. Pendleton, D. T. and K. Schmuds. 1979. Rangeland, range condition and erosion. Paper presented at the Society for Range Management 32nd Annual Meeting, Casper, Wyoming, February 12-15, 1979.

241. U.S.D.A. Soil Conservation Service. 1976. South Dakota land use -- 1975 estimates. U.S.D.A. SCS, Huron, S.D. 65 p.

242. U.S.D.A. Soil Conservation Service. 1976. Estimated land use conversions in South Dakota. Grassland-cropland, cropland-grassland. July 1, 1975-June 30, 1976. U.S.D.A.-SCS, Huron, S.D. 35 p.

243. U.S.D.A. Soil Conservation Service. 1977. Estimated land use conversions in South Dako-a. Grassland-cropland, cropland-grassland. July 1, 1976-June 30, 1977. U.S.D.A.-SCS, Huron, S.D. 35 p.

244. U.S.D.A. Soil Conservation Service. 1978. Estimated land use conversions in South Dakota. Grassland-cropland, cropland-grassland. July 1, 1977-June 30, 1978. U.S.D.A.-SCS, Huron, S.D. 35 p.

245. U.S.D.A. Soil Conservation Service. 1979. Estimated land use conversions in South Dakota. Grassland-cropland, cropland-grassland. July 1, 1978-June 30, 1979. U.S.D.A.-SCS, Huron, S.D. 39 p.

246. U.S.D.A. Soil Conservation Service. 1980. Estimated land use conversions in South Dakota. Grassland-cropland, cropland-grassland. July 1, 1979-June 30, 1980. U.S.D.A.-SCS, Huron, S.D. 35 p.

247. Anders, L. J. 1976. Herbicides: Physiology, Biochemistry, Ecology. Vol. I. 2nd ed. Academic Press, New York. 608 p.

248. Anders, L. J. 1976. Herbicides: Physiology, Biochemistry, Ecology. Vol. II. 2nd Ed. Academic Press, New York. 564 p.

249. Scifres, C. J. 1976. Herbicide nomenclature and related terminology. J. Range Manage. 29:173-174.

250. U.S. Environmental Protection Agency, Office of Pesticides Programs. 1974. EPA Compendium of Registered Pesticides. Vol. I. Herbicides and Plant Regulators. Supt. of Doc., U.S. Govt. Print. Office, Washington, D.C.

251. Weed Sci. Soc. of Amer. Handbook Comm. 1974. Herbicide Handbook of the Weed Science Society of America, Champaign, Il. 430 pp.

252. Tietjen, H. P. 1976. Zinc phosphide: Its development as a control agent for black-tailed prairie dogs. U.S.D.I. Fish and Wildl. Ser. Spec. Sci. Rep., Wildl. 195. 14 p.

253. Ward, A. L., P. L. Hegdal, V. B. Richens, and H. P. Tietjen. 1967. Gophacide, a new pocket gopher control agent. J. Wildl. Manage. 31:332-338.

254. Heidmann, L. J. 1963. Deer repellants are effective on ponderosa pine in the southwest. J. Forestry 61:53-54.

255. Haas, H. J., and W. O. Willis. 1968. Conservation bench terraces in North Dakota. Trans. ASAE 11:396-398.

256. Caldwell, M. M. 1980. Plant requirements for prudent grazing. National Research Council, Commission on Natural Resources, Committee on Developing Strategies for Rangelands Management, Forage Allocation Workshop, November 17-19, 1980, Albuquerque, N.M.

257. Ueckert, D. N. 1973. Effects of leaf-footed bugs on mesquite reproduction. J. Range Manage. 26:227-229.

258. Ueckert, D. N. 1973. Natural control of mesquite on Texas rangeland by insects. Southern Weed Sci. Soc., Proc. 25:453-457.

259. Ueckert, D. N. 1974. Influence of defoliation by the cutworm _Melipotis idomita_ on control of honey mesquite with 2,4,5-T in west Texas. J. Range Manage. 27:153-155.

260. Ayensu, E. S., and R. A. DeFilipps. 1978. Endangered and Threatened Plants of the United States. Smithsonian Institution, Washington, D.C. 403 p.

261. Van Dyne, G. M. and Z. Abramsky. 1975. Agricultural systems models and modeling: an overview, pp. 23-106. _In_: G. E. Dalton (Ed.) Study of Agricultural Systems. Applied Sci. Publ., Ltd. London. 441 p.

262. Van Dyne, G. M. 1980. Reflections and projections, pp. 881-921. In: A. J. Breymeir and G. M. Van Dyne (Eds.) Grasslands, Systems Analysis and Man. Cambridge Univ. Press.

263. Van Dyne, G. M. 1978. Foreword: perspectives on the ELM model and modelling effort, pp. v-xxii. In: G. S. Innis (Ed.) Grassland Simulation Model. Ecological Studies, Vo. 26. Springer-Verlag, New York.

264. Van Dyne, G. M. 1975. Some procedures, problems, and potentials of systems-oriented, ecosystem-level research programs, pp. 4-58. In: Procedures and Examples of Integrated Ecosystem Research. Papers presented to the Swecon Seminar, May 1973. Tech. Rep. 1. Barrskogslandskapets Ecologi: Swedish Coniferous Forest Project. Uppaala, Sweden.

265. Johnson, C. M. 1980. Computer techniques for land management planning. U.S.D.A. Forest Service. Res. Note RM-387. 4 p.

266. Swartzman, G. L., and G. M. Van Dyne. 1972. An ecologically based simulation--optimization approach to natural resource planning. Annual Rev. of Ecol. and Systematics, 3:347-398.

267. Redetzke, K. A., and G. M. Van Dyne. 1976. A matrix model of a rangeland grazing system. J. Range Manage. 29:425-430.

268. Woodworth, B. M. 1973. Optimizing the calf mix on range lands with linear programming. J. Range Manage. 26:175-178.

269. Evans, G. R. 1978. Systems approach for land resource analysis and planning of limited renewable natural resources. J. Anim. Sci. 46:819-822.

270. D'Aquino, S. A. 1974. Optimum allocation of resources: a programming approach. J. Range Manage. 27:228-233.

271. D'Aquino, S. A. 1974. A case study for optimal allocation of range resources. J. Range Manage. 27:228-233.

272. Bottoms, K. E. and E. T. Bartlett. 1975. Resource allocation through goal programming. J. Range Manage. 28:442-447.

273. Bell, E. F. 1976. Goal programming for land use planning. U.S.D.A. For. Serv. Gen. Tech. Rep. PNW-53. 12 p.

274. Beetle, A. A. 1970. Recommended Plant Names. Wyo. Agr. Exp. Sta. Res. J. 31, Univ. of Wyoming, Laramie.

275. Shetler, S. G. and L. E. Skog (Eds.). 1978. A Provisional Checklist of Species for Flora, North America (Revised). Missouri Botanical Garden.

276. Great Plains Flora Association. 1977. Atlas of the Flora of the Great Plains. Iowa State Univ. Press, Ames.

277. Renner, F. G., E. C. Crafts, T. C. Hartman, and L. Ellison. 1938. A selected bibliography on management of western ranges livestock, and wildlife. U. S. Dept. Agri. Misc. Pub. 281.

278. Vallentine, J. F. (Ed.). 1978. U.S.-Canadian Range Management, 1935-1977. A Selected Bibliography on Ranges, Pastures, Wildlife, Livestock, and Ranching. Oryx Press, Phoenix, Arizona.

279. Heerwagen, A. J. 1971. A Selected Bibliography of Natural Plant Communities in 11 Midwestern States. Soil Conserv. Service, U. S. Dept. Agr. Misc. Pub. 1205.

280. Blanchet, K., A. Quesada, L. Erickson, B. Hendricks, P. Nalluswami, and E. Taylor. 1973. An abstract bibliography on shortgrass and mixed-grass prairie ecosystems. U. S. I.B.P. Grassland Biome Tech. Rept. 236.

281. Wali, M. K. (Ed.). n.d. Native Grassland Ecosystems East of the Rocky Mountains in North America: A Preliminary Bibliography. Univ. of North Dakota Press, Fargo.

282. Carpenter, J. R. 1940. The grassland biome. Ecol. Monog. 10:617-684.

283. Clements, F. E. and V. E. Shelford. 1939. Bio-ecology. John Wiley and Sons, New York.

284. Shantz, H. L. and R. Zon. 1924. Natural Vegetation. U.S. Dept. Agri., Atlas of American Agriculture, Part 1, Sec. E.

285. Livingston, B. E. and F. Shreve. 1921. The Distribution of Vegetation in the United States as Related to Climatic Conditions. Carnegie Inst. Washington, Pub. 284.

286. Webb, W. P. 1931. The Great Plains. Ginn and Co., New York.

287. Dale, E. E. 1930. The Range Cattle Industry. Univ. Okla Press, Norman.

288. Osgood, E. S. The Day of the Cattleman. Univ. Minn. Press, Minneapolis. New Edition, 1957. Univ. Chicago Press, Chicago.

289. Von Richtofen, W. B. 1885. Cattle-Raising on the Plains of North America. D. Appleton and Co., New York. New Edition, 1964. Univ. Okla. Press, Norman.

290. Roe, F. G. 1955. The Indian and the Horse. Univ. Okla. Press, Norman.

291. Kraenzel, C. F. 1955. The Great Plains in Transition. Univ. Okla. Press, Norman.

292. Athearn, R. G. 1960. High Country Empire. Univ. Nebraska Press, Lincoln.

293. Dary, D. A. The Buffalo Book. Swallow Press, Inc., Chicago.

294. Roe, F. A. 1951. The North American Buffalo. Univ. of Toronto Press, Toronto.

295. Hornoday, W. T. 1889. The extermination of the American bison, pp. 367-584. In: Smithsonian Institution. Annual Report for 1887. Smithsonian Inst., Washington, D. C.

296. Brown, D. 1970. Bury My Heart at Wounded Knee. An Indian History of the American West. Holt, Rinehart and Winston, New York.

297. Dyksterhuis, E. J. 1972. Past and present of range management, pp. 7-11. In: Silver Anniv. Symp. Proc. Dep. Range Sci., Texas A & M Univ., College Station, March 20, 21, 1972. Texas A & M Univ. Press, College Station.

298. Sharp, L. A. and K. D. Sanders. 1978. Rangeland Resources of Idaho. A Basis for Development and Improvement. Univ. Idaho Forest, Wildlife and Range Exp. Sta. Contr. 114, Moscow.

299. Forest Service, Division of Range Research, U. S. Dep. Agr. 1944. The history of western range research. Agr. Hist. 18:127-143.

300. Coombs, J. 1980. Renewable sources of energy (carbohydrates). Outlook on Agr. 10:235-245.

301. Hall, D. O. 1980. Renewable resources (hydrocarbons). Outlook on Agr. 10:246-254.

302. Schumacher, C. M. 1974. The Great Plains -- wet or dry? J. Soil and Water Conserv. 29:156-159.

303. Thorthwaite, C. W. 1931. The climates of North America according to a new classification. Geogr. Rev. 21:633-655.

304. Kramer, F. L. 1963. The Koeppen dry/humid boundary: Preliminary test of the Patton formula. Prof. Geogr. 15:13, 14.

305. Oliver, J. E. 1973. Climate and Man's Environment. John Wiley and Sons, New York. 517 p.

306. Clawson, M. 1950. The Western Range Livestock Industry. McGraw-Hill Book Co., Inc., New York.

307. Lewis, J. K. 1973. Improving the efficiency of calf production in the 80s using resources of the Great Plains: An educator's view, pp. B-1-29. In: F. H. Baker (Ed.) Great Plains Beef Symposium, May 29-31, 1973. Lincoln, Neb. Great Plains Agr. Council Publ. 63.

308. Lackey, E. E. 1937. Annual-variability rainfall maps of the Great Plains. Geogr. Rev. 27:665-670.

309. Bowman, I. 1935. Our expanding and contracting desert. Geogr. Rev. 25:43-61.

310. Campbell, R. S. 1936. Climatic Fluctuations, pp. 135-150. In: U.S. Forest Service, The Western Range, U.S. Congress, 74th, 2d sess., 5 Doc. 199.

311. Clements, F. E. 1921. Drought periods and climatic cycles. Ecology 2: 181-188.

312. Kinder, J. B. 1923. The climate of the Great Plains as a factor in their utilization. Ann. Ass. Amer. Geogr. 13:67-80.

313. Hoyt, J. C. 1936. Droughts of 1930-1934. U.S. Geol. Surv. Water Supply Paper 680. 160 p.

315. Thornthwaite, C. W. 1941. Climate and Settlement in the Great Plains. Climate and Man Yearbook of Agriculture, 1941. pp. 177-187.

316. Sears, P. B. 1935. Deserts on the March. Univ. of Okla Press, Norman. 231 pp.

317. Clements, F. E. 1938. Climatic cycles and human populations in the Great Plains. Sci. Monthly 47 No. 3 Sep. 1938, pp. 222-245. In: B. W. Allred and E. S. Clements (Eds.) 1949. Dynamics of Vegetation. H. W. Wilson Co., New York. 296 p.

318. Whitman, W. C., H. C. Hanson and R. Peterson. 1943. Relation of drought and grazing to North Dakota range lands. N. D. Agr. Exp. Sta. Bull. 320.

319. Weaver, J. E. 1961. Return of midwestern grassland to its former composition and stabliization. Occ. Papers, C. C. Adams Center for Ecological Studies, No. 3, May 21, 1961. Western Michigan Univ., Kalamazoo. 15 p.

320. Kincer, J. B. 1935. Man's responsibility for droughts in the Great Plains. Bull. Am. Meterol. Soc. 16:146-148.

321. Ellison, L. and E. J. Woolfolk. 1937. Effects of drought on vegetation near Miles City, Montana. Ecology 18(3):329-336.

322. Palmer, W. C. and L. M. Denny. 1971. Drought bibliography. NOAA Tech. Memo. EDS 20. U.S. Dept. Com., U.S. Govt. Print. Office, Washington, D. C.

323. Rosenberg, N. J. (Ed.). 1978. North American Droughts. Amer. Assoc. Adv. Sci. Selected Symposium 15, Washington, D. C.

324. Felch. R. E. 1978. Drought: characteristics and assessment, pp. 25-42. In: N. J. Rosenberg (Ed.) North American Droughts. Amer. Assoc. Adv. Sci. Selected Symposium 15, Washington, D. C.

325. Palmer, W. C. 1965. Meterological drought. U.S. Dept. Com. Weather Bur. Res. Paper 45.

326. Miewald, R. D. 1978. Social and political impacts of drought, pp. 79-101. In: N. J. Rosemberg (Ed.) North American Droughts. Amer. Assoc. Adv. Sci. Selected Symposium 15, Washington, D. C.

327. Haas, J. E. 1978. Strategies in the event of drought, pp. 103-122. In: N. J. Rosenberg (Ed.) North American Droughts. Amer. Assoc. Adv. Sci. Selected Symposium 15, Washington, D. C.

328. Weaver, J. E. and F. W. Albertson. 1956. Grasslands of the Great Plains. Johnson Publ. Co., Lincoln, Nebraska.

329. Coupland, R. T. 1958. The effects of fluctuations in weather upon the grasslands of the Great Plains. Bot. Rev. 24:273-317.

330. Hurtl, L. E. 1951. Managing Northern Great Plains cattle ranges to minimize effects of drought. U.S.D.A. Cir. 865.

331. Whitman, W. C., H. C. Hanson, and R. Peterson. 1943. Relation of drought and grazing to North Dakota rangelands. N.D. Agric. Exp. Sta. Bull. 320.

332. Albertson, F. W. and G. W. Tomanek. 1965. Vegetation changes during a 30-year period on grassland communities near Hays, Kansas. Ecol. 46: 714-720.

333. Thompson, L. M. 1973. Cyclical weather patterns in the middle latitudes. J. Soil and Water Conserv. 28:87-89.

334. Albertson, F. W., G. W. Tomanek, and A. Riegel. 1957. Ecology of drought cycles and grazing intensity on grasslands of the central Great Plains. Ecol. Monogr. 27:27-44.

335. Lommasson, T. 1947. The influence of rainfall on the prosperity of eastern Montana, 1878-1946. U. S. Forest Service Region One Misc. Publ. No. 7, Missoula, Montana.

336. Bryson, R. A. and T. J. Murray. 1977. Climates of Hunger. Univ. of Wisconsin Press, Madison. 171 p.

337. Kendall, H. M. 1935. Notes on climatic boundaries in the eastern United States. Geogr. Rev. 25(1):117-124.

338. National Research Council, National Academy of Science. 1975. Understanding Climatic Change: A Program for Action. U.S. Committee for the Global Atmospheric Research Program, National Research Council, Washington, D. C.

339. Bryson, R. A., J. E. Ross, R. W. Hougas, and L. E. Engelbert. 1974. Climatic change and agricultural responses: A statement on research and technological priorities between now and the year 2000. A Report to the National Science Foundation. Institute for Environmental Studies, Univ. of Wisconsin, Madison.

340. Lamb, H. H. 1966. The Changing Climate. Methuen, London.

341. Lawson, M. P. 1974. The Climate of the Great American Desert. Reconstruction of the Climate of the Western Interior United States, 1800-1850. Univ. of Nebraska Press, Lincoln.

342. Van Royen, W. 1937. Prehistoric Droughts in the Central Great Plains. Geogr. Rev. 26:637-650.

343. White, E. M. 1960. Conditions for cliff dune formation and the climatic implications. Plains Anthropologist 5-10.

344. Zingg, A. W. 1953. Speculations on climate as a factor in the wind erosion problem of the Great Plains. Kansas Acad. Sci., Trans. 56(3): 371-377.

345. Wills, G. F. 1946. Tree ring studies. N. D. Agric. Exp. Sta. Bull. 338.

346. Weakley, H. E. 1962. History of drought in Nebraska. J. Soil and Water Cons. 17:271-273, 275.

347. Wells, P. V. 1970. Postglacial vegetational history of the Great Plains. Science 167:1574-1582.

348. Sawyer, J. S. 1971. Possible effects of human activity on world climate. Weather, Lond., 26(6):251-262.

349. Pendleton, D. F. and G. M. Van Dyne. 1980. Research issues in grazing lands under changing climate. A report prepared for the Climate Project of the Amer. Assoc. Adv. Sci. Range Sci. Dept., Colo. State Univ., Ft. Collins.

350. Manabe, S., and R. T. Wetherald. 1980. On the distribution of climate change resulting from an increase in CO_2 content of the atmosphere. J. Atmos. Sci. 37:99-118.

351. Schlesinger, M. E. and W. L. Gates. 1979. Numerical simulation of the January and July global climate with the OSU two-level atmospheric general circulation model. Report No. 9, Climatic Research Institute, Ore. State Univ., Corvallis.

352. Gates, W. L. and K. A. Cook. 1979. Appendix B, Preliminary analysis of experiments in the climatic effects of increased CO_2 with the OSU atmospheric general circulation model. In: Climatic Research Institute, Dept. Atmos. Sci., Research on the Dynamics of Climate. Research Proposal to the National Science Foundation, October 1979.

353. Williams. J. 1980. Anomalies in temperature and rainfall during warm arctic season as a guide to the formulation of climatic scenarios. Climatic Change 2. (In press).

354. Wigley, T. M. L., P. D. Jones, and P. M. Kelly. 1980. Scenario for a warm high-CO_2 world. Nature 283:17-21.

355. Kellogg, W. W. 1977. Effects of human activities on global climate. WMO Tech. Note No. 156. Geneva, Switzerland. 47 p.

356. Bolin, B., E. T. Degens, S. Kempe, and P. Ketner (Eds.). 1979. The global carbon cycle. John Wiley and Sons, Great Britain. 491 p.

357. National Research Council. 1979. Carbon dioxide and climate: A scientific assessment. Report of an Ad Hoc Study Group on Carbon Dioxide and Climate, Climate Research Board. NRC, Washington, D. C.

358. Emaneul, W. R., J. S. Olson and G. G. Killough. 1980. The expanded use of fossil fuels by the U. S. and the global carbon dioxide problem. J. Environ. Manage. 10:37-49.

359. Strain, B. R. (Ed.). 1978. Report of the Workshop of anticipated plant legumes to global carbon dioxide enrichment. Durham, N. C.

360. Mitchell, J. M., Jr. 1973. The natural breakdown of the present interglacial and its possible intervention by human activities. Quaternary Res. 2:436-445.

361. Watt, K. E. F. 1973. Principles of Environmental Science. McGraw-Hill Book Co., New York.

362. Bryson, R. A. and G. J. Dittberver. 1976. A non-equilibrium model of hemispheric mean surface temperature. J. Atmos. Sci. 33:2094-2106.

363. Clements, F. E. 1920. Plant Indicators. Carnegie Inst. Wash. Pub. 290.

364. Launchbaugh, J. L. 1972. Effect of fire on shortgrass and mixed prairie species. Proc. Tall Timbers Fire Ecol. Conf. 12:129-151.

365. Carpenter, J. R. 1940. The grassland biome. Ecol. Monogr. 10:617-684.

366. Clements, F. E. and V. E. Shelford. 1939. Bio-ecology. John Wiley and Sons, New York.

367. Shantz, H. L., and R. Zon. 1924. Natural vegetation. U. S. Dept. Agric., Atlas of Amer. Agric. Part 1, Sec. E.

368. Livingston, B. E. and F. Shreve. 1921. The Distribution of Vegetation in the United States as Related to Climatic Conditions. Carnegie Inst. Washington, Pub. 284.

369. Kuchler, A. W. 1964. Potential natural vegetation of the conterminous United States. (Manual and map). Amer. Geogr. Soc. Spec. Pub. 36, 1965 rev. 116 p. New York.

370. Kuchler, A. W. 1970. Potential Natural Vegetation, pp. 89-91. The National Atlas of the United States of America. U.S.D.I. Geol. Surv., Washington, D. C.

371. Garrison, G. A., A. J. Bjustad, D. A. Duncan, M. E. Lewis, and D. R. Smith. 1977. Vegetation and environmental features of forest and range ecosystems. Forest Service, U. S. Dept. Agric., Agric. Handb. 475.

372. Aandahl, A. R. 1972. Soils of the Great Plains. (Map). U.S.D.A. Soil Conservation Service, Lincoln, Nebraska.

373. Dyksterhuis, E. J. 1948. The western cross timbers. Ecol. Monogr. 18:325-376.

374. Dyksterhuis, E. J. 1957. The savanna concept and its use. Ecol. 38: 435-442.

375. Blaisdell, J. P., V. L. Duvall, R. W. Harris, R. D. Lloyd, and E. H. Reid. 1970. Range research to meet new challenges and goals. J. Range Manage. 23:227-234.

376. Stewart, G. 1936. History of range use, pp. 119-133. In: U. S. Forest Service. The Western Range. 74th Congr. 2d Sess. Doc. No. 199.

377. Chapline, W. R. 1936. Excessive stocking, pp. 151-171. In: U. S. Forest Service. The Western Range. 74th Congr. 2d Sess. Doc. No. 199.

378. U. S. Forest Service. 1936. The Western Range. 74th Congr. 2d Sess. Doc. 199.

379. Wentworth, E. N. 1948. America's Sheep Trails. Iowa State College Press, Ames.

380. Malin, J. C. 1948. The Grassland of North America. Prolegomena to Its History. James C. Malin Publ., 1541 Univ. Drive, Lawrence, Kansas.

381. Sherratt, A. (Ed.). 1980. The Cambridge Encyclopedia of Archaeology. Crown Publishers, Inc., New York.

382. Forest Service. 1975. The Nation's Renewable Resources -- An Assessment, 1975. U.S.D.A. Forest Service, Forest Resource Rep. No. 21.

383. U. S. Dept. Agriculture. 1980. Soil and Water Resources Conservation Act. Appraisal 1980. Review Draft Part 1. U.S. Dept. Agric., Washington, D. C.

384. Dyksterhuis, E. J. 1958. Ecological principles in range evaluation. Bot. Rev. 24:253-272.

385. Dyksterhuis, E. J. 1949. Condition and management of rangelands based on quantitative ecology. J. Range Manage. 2:104-115.

386. Parker, K. W. 1954. Application of ecology in the determination of range condition and trend. J. Range Manage. 7:14-23.

387. Shiflet, T. M. 1973. Range sites and soils in the United States, pp. 26-33. Proc. Third U.S.-Austr. Rangelands Panel.

388. U.S.D.A. Soil Conservation Service. 1976. National Range Handbook. U.S.D.A. Soil Cons. Serv., Washington, D. C.

389. United States Department of Agriculture. 1980. Soil and Water Resources Conservation Act. Program Report and Environmental Impact Statement (Review Draft). U.S. Dep. Agr., Washington, D. C.

390. Ramsey, C. W. 1965. Potential economic returns from deer as compared with livestock in the Edwards Plateau region of Texas. J. Range Manage. 18:247-250.

391. Gartner, F. R. and K. E. Severson. 1972. Fee hunting in South Dakota. J. Range Manage. 25:234-237.

392. Teer, J. G. 1975. Commercial uses of game animals on rangelands of Texas. J. An. Sci. 40:1000-1008.

393. Atlebury, J. T., J. C. Kroll, and M. H. Legg. 1977. Operational characteristics of commercial exotic big game hunting ranches. Wildl. Soc. Bul. 5:179-184.

394. National Geographic Society. 1975. Wilderness U.S.A., 3rd Ed. National Geogr. Soc., Washington, D. C.

395. U.S.D.A. Forest Service. 1964. The National Grasslands Story. U.S.D.A. Prog. Aid 607.

396. Rangeland Reference Area Committee. 1975. Rangeland Reference Areas. Range Sci. Ser. 3. Society for Range Management, Denver, Colorado.

397. Van Bruggen, T. 1979. Prairie preserves: valuable relicts? Rangelands 1:14-17.

398. Coupland, R. T. (Ed.). 1979. Grassland Ecosystems of the World: Analyses of Grasslands and Their Uses. Cambridge Univ. Press. 401 p.

399. Breymeyer, A. I. and G. M. Dan Dyne (Eds.). 1980. Grasslands, Systems Analysis and Man. Cambridge Univ. Press. 950 p.

400. Innis, G. S. (Ed.). 1978. Grassland Simulation Model. Ecological Studies No. 26. Springer-Verlag, New York. 298 p.

401. French, N. R. (Ed.). 1979. Perspectives in Grassland Ecology. Results and Applications of the US/IBP Grassland Biome Study. Ecological Studies No. 32. Springer-Verlag, New York. 204 p.

402. Van Dyne, G. M., F. M. Smith, R. L. Czaplewski and R. G. Woodmansee. 1978. Analyses and synetheses of grassland ecosystem dynamics, pp. 1-79. In: J. S. Singh and B. Gopal (Eds.) Glimpses of Ecology (Professor R. Misra Commemoration Volume). Intern. Sci. Publications, Jaipur, India. 592 p.

403. Van Dyne, G. M., L. A. Joyce, B. K. Williams and J. E. Kantz. 1977. Data, Hypotheses, Simulation and Optimization Models and Model Experiments for Shortgrass Prairie Grazinglands: A Summary of Recent Research. Report to the Council on Environmental Quality, Exec. Off. of the President. Washington, D. C. 770 p. (NTIS Accession No. PB-273 738)

404. Risser, P. G., E. C. Birney, H. D. Blocker, W. May, W. J. Parton, and J. A. Wiens. In Press. The True Prairie Ecosystem. Dowden, Hutchinson and Ross.

405. Severson, K. E. and F. R. Gartner. 1972. Problems in commercial hunting systems: South Dakota and Texas compared. J. Range Manage. 25:342-345.

406. Heady, E. O. and J. L. Dillon. 1961. Agricultural Production Functions. Iowa State Univ. Press, Ames.

407. Agrawal, R. C. and E. O. Heady. 1972. Operations Research Methods for Agricultural Decisions. Iowa State Univ. Press, Ames.

408. Innis, G. S. 1975. Simulation models of grasslands and grazing lands. In: M. Numata (Ed.) Ecology of Grasslands and Bamboolands in the World. Springer-Verlag, New York.

409. Van Dyne, G. M. 1966. Application of multiple linear regression and linear programming in renewable resources analysis. J. Range Manage. 19:356-362.

410. Van Dyne, G. M. and K. R. Rebman. 1967. Maintaining a profitable ecological balance, p. P<6.-6.9. In: R. M. Thrall, J. R. Mortimer, K. R. Rebman and R. F. Baum (Eds.) Some Mathematical Models in Biology. Univ. Mich. Rep. 40241-R-7 (5TOI-GM01456-02), East Lansing.

411. Child, R. D. and G. R. Evans. 1976. COPLAN. Range Sci. Dep. Sci. Ser. No. 19. Colorado State Univ., Ft. Collins. 73 p.

412. Wiegert, R. G. 1975. Simulation models of ecosystems. Ann. Rev. Ecol. Syst. 6:311-338.

413. Van Dyne, G. M. and P. T. Kortopates. 1980. Quantitative frameworks for forage allocation. National Academy of Sciences, Nat. Res. Council, Board on Agr. and Renew. Res., Comm. on Developing Strategies for Rangelands Manage. Forage Allocation Workshop, Nov. 17-19, 1980. Albuquerque, N.M.

414. Martinson, F. 1980. Linear programming approach to forage allocation. National Academy of Sciences, Nat. Res. Council, Board on Agr. and Renew. Res., Comm. on Developing Strategies for Rangelands Manage. Forage Allocation Workshop, Nov. 17-19, 1980. Albuquerque, N.M.

415. Innis, G. (Ed.). Grassland Simulation Model. Ecological Studies Vol. 26. Springer-Verlag, New York.

416. Van Dyne, G. M., L. A. Joyce and B. K. Williams. 1978. Models and the formulation and testing of hypotheses in grazing land ecosystem management, pp. 41-84. In: M. W. Holdate and M. J. Woodman (Eds.) The Breakdown and Restoration of Ecosystems. Plenum Press, New York.

417. U.S.D.A. Forest Service. 1978. Management of Prairie Dogs on Lands Administered by the Supervisor of the Nebraska National Forest. Final Environmental Statement. U.S.D.A. Forest Service, Nebraska National Forest, Chadron, Nebraska. 188 p.

418. Uresk, D. 1980. Prairie-dog cattle interactions. Talk presented to interested scientists in Conata Basin, May 15, 1980. (Available from Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S.D.A., School of Mines Campus, Rapid City, SD.)

419. Merriam, C. Hart. 1901. The Prairie Dogs of the Great Plains, pp. 257-
270. Yearbook, Dept. of Agr. 1901.

420. U.S.D.A. Forest Service. 1977. RPA-79 Assessment. Book of Procedures, Framework for Supply Analysis, Range and Multi-resource Use Interaction. Elements. U.S.D.A. Forest Service, Washington, D. C.

421. Harlan, J. C., D. W. Deering, R. H. Haas and W. E. Boyd. 1979. Determination of range biomass using Landsat. Proc. 13th Intern. Symp. Remote Sensing of Env. 2:659-673. Ann Arbor, Mich.

422. Chiu, H., and W. Collins. 1978. A spectroradiometer for airborne remote sensing. Photogram. Eng. and Remote Sensing 44:507-517.

423. Tucker, C. J. 1977. Spectral estimation of grass canopy variables. Remote Sens. Environ. 6:11-26.

424. Pearson, P. L., L. D. Miller, and C. J. Tucker. 1976. Hand-held spectral radiometer to estimate gramineous biomass. Appl. Optics 15: 416-418.

425. Tucker, C. J. 1980. A spectral method for determining the percentage of green herbage material in clipped samples. Remote Sens. Environ. 9:175-181.

426. U.S.D.A. Soil Conservation Service. 1979. Technical Guide for South Dakota. U.S.D.A. Soil Cons. Service, Huron, S.D.

427. U.S.D.A. Agricultural Stabilization and Conservation Service. 1979. The Agricultural Conservation Program. 1978 Program Year. U.S.D.A., A.S.C.S., Washington, D. C.

428. Smith, R. E. 1958. Natural History of the Prairie Dog in Kansas. Museum of Natural History and State Biological Survey. Univ. of Kansas, Lawrence.

429. King, J. 1955. Social behavior, social organization, and population dynamics in a black-tailed prairie dog town in the Black Hills of South Dakota. Contrib. Lab. Vert. Biol. 67. Univ. Michigan, Ann Arbor.

430. Gray, J. R. 1968. Ranch Economics. Iowa State Univ. Press, Ames.

431. Bartlett, E. T. and W. J. Clawson. 1978. Profit, meat production or efficient use of energy in ranching. J. An. Sci. 46(3):812-818.

432. Cook, C. W. 1977. Use of rangelands for future meat production. J. An. Sci. 45:1476-1482.

433. Cook, C. W. 1972. Energy budget for rabbits compared to cattle and sheep. Colorado State Univ. Range Sci. Dep., Range Sci. Ser. 18.

434. Cook, C. W., A. H. Denham, E. T. Bartlett and R. D. Child. 1976. Efficiency of converting nutrients and cultural energy in various feeding and grazing systems. J. Range Manage. 29:186-191.

435. Pimentel, D. L., L. E. Hurd, A. C. Ballotti, M. J. Forster, I. W. Oka, O. D. Sholes, and R. J. Whitman. 1973. Corn, food and the energy crisis. Science 182:443-449.

436. Burch, W. R., Jr. 1980. The rhetoric of biology -- some dimensions of range resource allocation. Nat. Acad. Sci., Nat. Res. Council, Board on Agr. and Renew. Res., Comm. Developing Strategies for Rangeland Manage. Forage Allocation Workshop, Nov. 17-19, Albuquerque, N. M.

437. Steinhart, J. S. and C. E. Steinhart. 1974. Energy use in the U. S. food system. Science 184:307-316.

438. Jensen, Neil F. 1978. Limits to growth in world food production. Science 201:317-320.

439. Hust, E. 1974. Food-related energy requirements. Science 184:132-138.

440. Ward, G. M., P. L. Knox and B. W. Hobson. 1977. Beef production option and requirements for fossil fuel. Science 198:265-271.

441. Pimentel, D., P. A. Olteneau, M. C. Nesheim, J. Krummel, M. S. Alber, and S. Chick. 1980. The potential for grass-fed livestock: resource constraints. Science 207:843-848.

442. Schuster, J. L. 1979. Opportunities to improve rangelands, pp. 46-49. Proc. Symposium on Rangeland Policies for the Future, Jan. 28-31, 1979, Tucson, Ariz.

443. Office of Personnel Management. 1980. Qualification Standards. Range Conservation Series GS454. TS 179, July 1980. U.S. Govern. Print. Off., Washington, D. C. 8 p.

444. Soil Conservation Service. 1978. National Conservation Planning Manual, Title 11, 2nd ed. U.S.D.A. Soil Conservation Service, Washington, D. C.

445. U.S.D.A. Agricultural Stabilization and Conservation Service. 1979. The Agricultural Conservation Program, 1978 Program Year. A Statistical Summary. U.S.D.A., A.S.C.S., Washington, D. C.

446. National Planning Committee of Agricultural Research Policy Committee. 1977. Range and Forage Research Needs for Red Meat Production. U.S. Dep. Agr. and Nat. Assoc. State Univ. and Land Grand Colleges.

447. Merrill, J. L. 1979. Problems as opportunities for improvement, pp. 50-52. In: U.S. Dep. Agr., U.S. Dep. Int., Council Environ. Quality. Range Policies for the Future. Proc. Symp., Jan. 28-31, 1979, Tucson, Ariz.

448. Gray, J. R. 1979. Opportunities to improve rangeland economic incentives, costs and benefits, pp. 56-58. In: U.S. Dep. Agr., U.S. Dep. Int., Council Environ. Quality. Range Policies for the Future. Proc. Symp. Jan. 28-31, 1979, Tucson, Ariz.

449. Boykin, C. C. 1973. Reduction of unit cost of calf production, p. H-1-21. In: F. H. Baker (ed.) Great Plains Beef Symposium, May 29-31, 1973, Lincoln, Nebr. Great Plains Agr. Council Pub. 63.

450. Gray, J. R. 1971. Organization, Costs, and Income of Western Cattle and Sheep Ranches. N. M. Agr. Exp. Sta. Bul. 587.

451. Economist. 1980. Money and finance, special section. The Economist 277:1-24.

452. McIlvain, E. H. and M. C. Shoop. 1973. Use of farmed forage and tame pasture to complement native range, p. L1-19. In: F. H. Baker (ed.) Great Plains Beef Symp., May 29-31, 1973. Lincoln, Neb. Great Plains Agr. Council Pub. 63.

453. Lorenz, R. J. and G. A. Rogler. 1962. A comparison of methods of renovating old stands of crested wheatgrass. J. Range Manage. 15:215.

454. Lorenz, R. J. and G. A. Rogler. 1973. Fertilization and chemical manipulation of native and introduced species to increase production, p. M-1-19. In: F. H. Baker (ed.) Great Plains Beef Symp., May 29-31, 1973, Lincoln, Neb. Great Plains Agr. Council Pub. 63.

455. Council on Environmental Quality and Department of State. 1980. The Global 2000 Report to the President: Entering the Twenty-first Century. Vol. 2, The Technical Report. U.S. Govt. Print. Off., Washington, D. C.

456. Council on Environmental Quality and Department of State. 1980. The Global 2000 Report to the President: Entering the Twenty-first Century. Vol. 1. The Summary Report. U.S. Govt. Print. Off., Washington, D. C.

457. Bommer, D. F. R. 1978. Rangeland resources and world food needs, p. 5, 6. Proc. First Intern. Rangeland Congress, Aug. 14-18, 1978, Denver, Colo., U.S.A.

458. United Nations World Food Conference. 1974. Assessment of the World Food Situation, Present and Future. E/CONF 65/3, Rome.

459. Baumer, M. C. 1978. Environmental impacts of rangeland uses, p. 17-20. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, Denver, Colo., U.S.A.

460. Northern Great Plains Resources Program Staff. 1975. Effects of Coal Development in the Northern Great Plains. Northern Great Plains Resources Program. Denver, Colo. 165 p.

461. Ries, R. E., F. M. Sandoval and J. F. Power. 1978. Reestablishment of grasses on land disturbed by mining in the Northern Great Plains, p. 700-703. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, Denver, Colo.

462. McWilliams, J. L. and P. E. Van Cleave. 1960. A comparison of crested wheatgrass and native grass mixtures seeded on rangeland in eastern Montana. J. Range Manage. 13:91-94.

463. Derscheid, L. A., W. Aanderud, and J. J. O'Connell. 1975. Alternative pasture and forage systems. S. D. Agr. Exp. Sta. Cir. 709.

464. Houston, W. R. and J. J. Urick. 1972. Improved spring pastures, cow-calf production, and stocking rate carryover in the Northern Great Plains. U.S.D.A. Tech. Bul. 1451.

465. Jefferies, N. W., R. L. Lang, M. May, and L. Leland. 1967. Cow-calf production on seeded and native range. Wyo. Agr. Exp. Sta. Bul. 472.

466. Krueger, C. R., R. A. Moore, and L. B. Embry. 1974. Cow-calf evaluation of native and tame pasture systems for six grazing seasons. Intern. Grassland Congr. Proc. Sect. Papers: Grassl. Utilization, 12:315-328.

467. Launchbaugh, J. L. 1971. Upland seeded pastures compared for grazing steers at Hays, Kansas. Kans. Agr. Exp. Sta. Bul. 548.

468. Polk, D. B., Jr., C. J. Scifres, J. L. Mutz. 1976. Establishment, production, and protein content of four grasses in south Texas. J. Range Manage. 29:240-243.

469. Byerly, T. C. 1977. Ruminant livestock research and development. Science 195:450.

470. Cook, C. W. 1976. Cultural energy expended in range meat and fiber production. J. Range Manage. 29:268-271.

471. Fitzhugh, H. A. 1978. Bioeconomic analysis of ruminant production systems. J. An. Sci. 46:797-806.

472. Fitzhugh, H. A. 1977. Sheep and goats as food and fiber resources--current and future. Proc. Workshop on Role of Sheep and Goats in Agricultural Development, U.S.A.I.D./Winrock International Livestock Research and Training Center, Morrilton, Ark.

473. Reid, J. T. 1970. Will meat, milk and egg production be possible in the future? Proc. Cornell Nutr. Conf., Buffalo, N. Y.

474. Thomas, G. W. 1975. A rangeman's critique of the World Food Conference. J. Range Manage. 28:86-89.

475. Stevens, D. M. and D. R. Hartley. 1976. Decline in Wyoming sheep industry--a partial explanation. Wyo. Agr. Exp. Sta. Res. J. 104. 41 p.

476. Tigner, J. R. and G. E. Larson. 1977. Sheep losses on selected ranches in southern Wyoming. J. Range Manage. 30:244-252.

477. Magleby, R. S. 1975. Sheep losses due to predators and other causes in the western United States. U.S.D.A. Econ. Res. Ser. Rep. 616.

478. Bahn, H. and J. O. Early. 1977. Estimating sustainable predation losses on Idaho range sheep operations. Ida. Agr. Exp. Sta. Bul. 577.

479. Talbot, L. M., W. J. A. Payne, H. P. Ledger, L. D. Verdcourt and M. H. Talbot. 1965. The meat production potential of wild animals in Africa. A review of biological knowledge. Tech. Comm. No. 16, Commonwealth Bureaux of Animal Breeding and Genetics. Edinborough.

480. Cole, R. S. 1974. Elk and bison management on the Oglalla Sioux Game Range. J. Range Manage. 27:484-485.

481. Winrock International Livestock Research and Training Center. 1978. The Role of Ruminants in Support of Man. Winrock International, Morrilton, Ark.

482. Gartner, F. R. 1978. Federal and state cooperation for improving rangelands through education, p. 111-113. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, Denver, Colo.

483. Cook, C. W. and C. D. Bonham. 1974. Analysis of range conservation academic training. J. Range Manage. 27:480-483.

484. U. S. Department of Agriculture, U. S. Department of Interior and Council on Environmental Quality. 1979. Rangeland Policies for the Future. Proc. Symposium, Jan. 28-31, 1979, Tucson, Ariz.

485. Interagency Ad-Hoc Committee on the Sense of the Symposium. 1979. The Sense of the Symposium on Rangeland Policies for the Future. A Report to Asst. Sec. Agr. for Cons. Res. and Ed., U.S.D.A., the Asst. Sec. Int. for Land and Water Res. and Pres. Council on Environ. Quality, Washington, D. C.

486. Box, T. W. 1979. The American rangelands: Their condition and policy implications for management, p. 16-22. In: U. S. Dep. Agr., U. S. Dep. Int., Council Environ. Qual. Range Policies for the Future. Proc. Symposium, Jan. 28-31, 1979, Tucson, Ariz.

487. Range Term Glossary Committee. 1964. A Glossary of Terms Used in Range Management. Society for Range Management, Denver, Colorado. 32 p.

488. Range Inventory Standardization Committee. 1980. Draft standard definitions and terminology. Rangelands 2:165-167.

489. Hanson, H. C. 1962. Dictionary of Ecology. Philosophical Library, Inc. Washington, D. C. 382 p.

490. Schwartz, C. F., E. C. Thor, and G. H. Elsner. 1976. Wildland Planning Glossary. U.S.D.A. Forest Service. Gen. Tech. Rep. PSW-13. 252 p.

491. Soil Science Society of America. 1971. Glossary of Soil Science Terms. Soil Science Society of America. Madison, Wisconsin. 28 p.

492. Woodmansee, R. G. 1974. Glossary of systems ecology terms. U.S.I.B.P. Grassland Biome Tech. Rep. 256.

493. Wallen, C. C. and M. D. Gwynne. 1978. Drought -- A challenge to rangeland management, p. 21-31. Proc. First Intern. Rangeland Congr., Aug. 14-18, 1978, Denver, Colo.

494. Charney, J. 1975. Dynamics of deserts and droughts in the Sahel. Quart. J. Roy. Meteor. Soc. 101:

495. Dyksterhuis, E. J. and E. M. Schmutz. 1947. Natural mulches or "litter" of grasslands: with kinds and amounts on a southern prairie. Ecol. 28:163-179.

496. Sampson, A. W. 1914. Natural revegetation based upon growth requirements and life history of the vegetation. J. Agr. Res. 3:93-147.

497. Jardine, J. T. and M. Anderson. 1919. Range management on the national forests. U.S.D.A. Bul. 790. 98 p.

498. Bennett, H. H. and W. R. Chapline. 1928. Soil erosion, a national menace. U.S.D.A. Cir. 33.

499. Forest Service. 1936. The Western Range. Senate Doc. 199, 74th Congress, 2nd Session. U. S. Government Print. Off., Washington, D. C.

500. CAST. 1976. Soil and Water Conservation Oversight. Council for Agricultural Science and Technology Rep. 60.

501. Bureau of Land Management. 1979. Managing the Public Rangelands. U.S.D.I., Bureau of Land Management, Washington, D. C. 43 p.

502. Secretary of Agriculture. 1979. Statement of Range Policy. U.S.D.A. Secretary's Memorandum 1999. 5 p.

503. Science and Education Administration. 1980. The Mission of Science and Education Administration — Agricultural Research. U.S.D.A., S.E.A., Washington, D. C. 36 p.

504. Pacific Consultants. 1969. The Forage Resource. A report produced for the Public Land Law Review Commission. Univ. of Idaho, Moscow.

505. U.S.D.A. 1971. Basic Statistics — National Inventory of Soil and Conservation Needs, 1967. U.S.D.A. Stat. Bul. 1461. 211 p.

506. Day, B. E. 1979. Range management, an ecological art, pp. 91-92. Proc. Symp. Rangeland Policies for the Future, January 28-31, 1979, Tucson, Ariz.

507. Edmunds, S. 1980. Three economic scenarios for the '80s. The Futurist 14:12-21.

508. U.S.D.A., Agr. Res. Serv. 1967. Challenges in forage and range research. U.S.D.A. Misc. Pub. 1053. 32 p.

509. McKell, C. M. 1967. Range research in the next 20 years. J. Range Manage. 21:155-157.

510. Joint Task Force of the U.S.D.A. and the State Universities and Land Grant Colleges. 1968. A National Program of Research for Forage, Range and Pasture. U.S.D.A. (limited publication). 93 p.

511. Agricultural Research Policy Advisory Committee. 1975. Research to Meet U. S. and World Food Needs, July 9-11, 1975, Kansas City, Mo. 326 p.

512. Klemmedson, J. O., R. Pieper, D. Dreyer, F. Mueggler, and M. Trlica. 1978. Research needs on western rangelands. J. Range Manage. 31:4-8.

513. U.S.D.A., Association of State College and University Research Organizations, and National Association of State Universities and Land Grant Colleges. 1978. National Program of Research for Forests and Associated Rangelands. U. S. Dep. Agr. ARM-H-1. 96 p.

514. National Cattlemen's Association. 1979. Beef cattle research needs and priorities. Beef Bus. Bul., November 2, 1979.

515. National Association of Conservation Districts. 1979. Pasture and Range Improvement Report. 38 p.

516. Range and Livestock Management Committee. 1967. Range and Livestock Management Problems of the Great Plains. Great Plains Agricultural Council, Lincoln, Neb. Mimeo. 11 p.

517. Great Plains Agricultural Council. 1976. Range Research Needs in the Great Plains. Great Plains Agric. Council Pub. 79. 60 p.

518. Ewing, S. A. and H. J. Gorz (Eds.). 1977. Range and forage research needs for red meat production in the north central region. Iowa Agr. Exp. Sta. Res. Bul. 583 (N. Centr. Reg. Res. Pub. 247).

519. NCA-6 Committee. 1977. Research needs in sheep, 1977 to 2000 A.D. Kans. Agr. Exp. Sta. Cir. 404 (N. Centr. Reg. Pub. 240).

520. NCA-6 Committee. 1977. Research needs in beef cattle, 1977 to 2000 A.D. Kans. Agr. Exp. Sta. Cir. 406 (N. Centr. Reg. Pub. 242).

521. Range and Livestock Management Committee. 1969. Report of the Forages and Feed Subcommittee. Report submitted to the Great Plains Agricultural Council, June 10, 1969.

522. Lewis, J. K. 1976. A Range Research Program for South Dakota State University. A Report submitted to Head, Animal Science Department, April 21, 1976. 47 p.